Part 17 / Strand 17
Science Teaching at the University Level

Editors: *Jenaro Guisasola & Paula Heron*

Part 17. Science Teaching at the University Level

University pedagogy. Teaching and learning at the university level.

INTERNATIONALIZATION AND SCIENCE TEACHER EDUCATION IN ACADEMIC PRODUCTIONS IN BRAZIL

Josane do Nascimento Ferreira Cunha[1,2], *Irene Cristina de Mello*[2]

[1]Federal Institute of Mato Grosso, Cuiabá, Brazil

[2]Federal University of Mato Grosso, Cuiabá, Brazil

Today's society is increasingly globalized and interconnected by digital technologies. Consequently, it needs a broad education capable of meeting the formative needs of 21st century citizens. This requires that the training of science teachers be up to date and in line with scientific and technological advances. In this perspective, we highlight the internationalization of higher education as a possibility to help these professionals to expand knowledge, intercultural relations, worldview, valorization, and respect among people. Therefore, and this study aimed to investigate the internationalization in science teacher education. For this, we conducted bibliographic research in the thesis/dissertation banks and scientific articles. This resulted in eight productions analyzed in three categories: internationalization in the perspective of comparative study, internationalization by international cooperation, and internationalization of the degree through academic mobility. We verified through this study the relevance of the international cooperation and international academic mobility programs to strengthen and expand the initial and continuing education of teachers. Furthermore, we note a low production and the need for more research in this area, considering the importance and contributions of internationalization in science teacher education and professional development.

Keywords: Teacher education, Internationalization of higher education, Sciences education

INTRODUCTION

Today's society is increasingly globalized and interconnected, with facilities to access diverse information and knowledge from anywhere in the world, to interact and learn from each other, and to exchange intercultural experiences. In this sense, favoring an education capable of developing a more effective, broad education that meets the formative needs of citizens in the 21st century are challenges.

This requires that the science teacher education is updated and connected with the formative, scientific and technological needs of global society. In this context, the internationalization of higher education defined by Knight (2004, p11) as "a process that integrates a global, intercultural and international dimension in the objectives, functions and offer of post-secondary education". The studies related to this process intensified in the 1990 in Brazil due to the possibility of improving the quality of education. Thus, universities seek to internationalize by increasing partnerships and international cooperation between countries. According to (Rodriguez & Massena,2020, p. 20) "the origin and advancement in the area of Science Education in Latin America has been a product of internationalization and cooperation in the higher education".

This internationalization process can occur through three main strategies: international academic mobility, internationalization of the curriculum and internationalization at home. International academic mobility abroad is the main form of internationalization worldwide. One of the best-known mobility programs is the European Action Scheme for the Mobility of *Students* (ERASMUS), the European Union Mobility Program. In Brazil, the largest academic mobility program was Science without Borders, which enabled the insertion of many higher education institution in the global context and accelerated the internationalization process of these institutions (Stallivieri, 2020).

Internationalization of the curriculum is the incorporation of international, intercultural and/or global dimensions into the content of the curriculum, as well as into the learning outcomes, assessment tasks, teaching methods and support services of a program of study" (Leask, 2015, p. 9). And internationalization at home is "the intentional integration of the international and intercultural dimension into the formal and informal curriculum for all students in home learning environments" (Beelen & Jones, 2015, p. 69). And it aims to include people who cannot afford to travel to another country either due to financial or other reasons. With the Covid-19 pandemic, internationalization at home through digital technologies has been the main way to continue with internationalization activities.

The internationalization of higher education is considered important in the training of science teachers, as it can expand knowledge, the worldview, the appreciation, and respect among peoples, such as on intercultural issues. And the teacher is the main responsible for the development of the internationalization of teaching, through the formulation or reformulation of the curriculum, development of teaching and learning strategies, conduct collaborative research with teachers from abroad and publication of scientific articles, receive in the classroom foreign students, among others (Stallivieri, 2016; Postiglione; Altbach, 2013) that help the student to develop intercultural competencies and skills.

However, in Brazil teachers are distant from the broader process of internationalization of teaching, although some actions have been taken (Ramos, 2018). From this perspective, this study aims to investigate the productions on internationalization in science teacher education in Brazil.

METHODOLOGY

The present study is characterized as bibliographic research with a qualitative approach, given that the focus is the process and not only the product (Bogdan & Biklen, 1994). The production of data occurred through a survey conducted in the Brazilian Digital Library of Theses and Dissertations (BDTD), in the theses database of the Coordination for the Improvement of Higher-Level Personnel (CAPES), in the Scielo database and in the Google academic in the last ten years. We used the descriptor: internationalization in science teacher education.

The data were analyzed according to the content analysis (Franco, 2005) which resulted in three categories: Internationalization by international cooperation, Internationalization of undergraduate degree by international mobility and Internationalization by comparative study.

RESULTS AND DISCUSSION

The investigation carried out in the databases of theses/dissertations and scientific articles resulted in eight productions, being two dissertations and six articles described in table 1.

Table 1. Productions related to internationalization and science teacher education.

Theme of productions	Author(s)/ year	Institution/ Scientific journal
The initial training of chemistry teachers and the internationalization of higher education in Brazil	Silva Junior (2017)	University of São Paulo (USP)
Initial training of chemistry teachers from the perspective of inclusive education: a dialogue between the curricular proposals of higher education institutions in the State of São Paulo and *the Teachers College* of Columbia University (USA)	Nascimento (2018)	University of São Paulo (USP)
Professional development and international cooperation for chemistry teachers: Evaluation of the intention of pedagogical change after continuing education in Porto, Portugal	Paiva et al. (2017)	New Chemical Magazine
Reflections on the effects of the transnationalization of curricula and the coloniality of knowledge/power in international cooperation: focus on science education	Cassiani (2018)	Education Sciences Journal
The international training experience in the Paulo Freire Academic Mobility Project for Students of University Teacher Training Programs of the Organization of Ibero-American States for Education, Science and Culture (OEI)	Tonello (2019)	Insignare Scientia Magazine
Repercussions of the International Degree Program on the academic and personal training of a group of chemistry graduates of the Federal University of Viçosa (MG)	Fialho, Santos and Catão (2019)	Education in Punto de Vista
Internationalization of Higher Education in the context of bachelor's degrees in Science Education	De Paula, Mello (2020)	Journal of the Amazon Network of Science and Mathematics – REAMEC
Latin American cooperation for the training of science teachers	Rodriguez and Massena (2020)	Essay Magazine

The dissertations were published in 2017 and 2018 by the Graduate Program of Education of the University of São Paulo (USP), a southeastern region of Brazil where publications in the area of science teaching predominate. Regarding the articles, we found six publications, one in 2017 and 2018, in 2019 and two in 2020. This indicates that the research related to this theme are still recent in Brazil and with few productions.

Internationalization by comparative study

In this category we found two dissertations, Silva Junior (2017) that verified how the initial training of chemistry teachers occurs in six courses from three state universities in São Paulo, taking into account the impacts of the Bologna process, which is an agreement signed by Ministers of Education from several European countries. The analysis showed the impact of international policies on education in Brazil and the similarities between the courses analyzed, indicating a pattern of compatibility and the possibility of academic mobility, as occurs among the countries that are part of the Bologna process (Silva Junior, 2017).

The second dissertation by Nascimento (2018), investigated how the issue of inclusion of students with disabilities is addressed in the initial training of chemistry teachers in the state of São Paulo, comparing with the international proposals of the teacher training program of teachers College at Columbia University in the United States. This evidenced that higher education institutions have not ensured a solid inclusive education for future chemistry teachers in do Brazil. This was also observed in the work of Bozi and Catão (2021) when studying the theme of professional training and experiences of chemistry teachers in the educational inclusion of the deaf and emphasized the urgency of discussions and training on inclusion in the initial and continuing education of chemistry teachers.

These two dissertations approached the internationalization from a comparative study perspective, this type of study seeks to verify the similarities and differences existing in a certain area in the international context, which can lead to the improvement of teacher education and provide cooperation and mobility between countries.

Internationalization by international cooperation

International cooperation is one of the ways to internationalize higher education and teacher training. It is considered an efficient strategy that collaborates to think about the construction a fair/sustainable society (Rodriguez & Massena, 2020).

The articles in this category addressed two Brazilian international cooperation programs: the Professional Development Program for Teachers of the Coordination of Personal Improvement of Higher Education (PDPP/CAPES), and the Program for Teacher Qualification and Portuguese Language Teaching in East Timor (PQLP /CAPES). These cooperation's occurred between Portuguese speaking countries and highlighted the relevance of international cooperation in science teacher training as described below:

> *It is possible to understand that the opportunity to "see and run the world" has been in itself generating gains, namely, at the level of the teachers' socio-professional knowledge (Paiva, et al., 2017).*
>
> *It can provide contact with important knowledge that contributes to citizenship education and peace consolidation (Cassiani, 2018, p.225).*
>
> *The processes of international cooperation in Latin America are fundamental, as they allow participants to build new visions about our reality, to live different academic and personal experiences, as well as to strengthen their regional identity and their professional, cultural, and personal formation (Rodriguez & Massena, 2020, p.22).*

These facts highlight the potential and benefits of internationalization through international cooperation in teacher education. This was also observed by Lopes (2020), when he stated that this type of partnership is already consolidated, and that it is important to invest in training strategies for the development of education professionals. However, we identified some threats and challenges in international cooperation that hinder the realization of this work, according to the excerpts below:

> *The heterogeneity of the participants*, the high risk of communication problems due to language *difficulties, lack of pedagogical resources (Paiva, et al., 2017).*
>
> *[...] the transnationalization of the curriculum, the effects of coloniality through textbooks, which can generate dependence and subalternization by vertically imposing universal, neutral, ahistorical knowledge, and without dialogue* of knowledges (Cassiani, 2018, p. 240).
>
> *[...] Need for articulation of professional training to personal training, approach of initial training courses to the school context, strengthening of the teaching identity and approach of education professionals to the community through contextualization, reflection, and research (Rodriguez & Massena, 2020, p. 22).*

Some of these difficulties have been identified in the context of cooperation in Portugal (Lopes, 2020), such as:

Lack of access to resources in the intervention context, lack of sustained dialogue specifically focused on the preparation of the missions with the institutional partners and as beneficiaries of the training program, lack of preparation of professionals both coordinators and teachers to work the curricula in this context, absence of memory and institutional organization, lack of articulation of work among collaborators (Lopes, 2020, p. 8).

The decontextualization of science teaching with the regional context was also mentioned in one of the studies. In this scenario, providing teacher education bringing science teaching closer to the local reality will favor a greater use and learning of the contents critically. The challenges and threats of cooperation need to be worked on to avoid the opposite effect. Therefore, it is important to monitor, plan, availability of adequate resources, training of coordinators and teachers, dissemination of the cooperation carried out in order to disseminate the information and improve the quality of these activities.

In addition, internationalization through international cooperation was seen as a means of professional teacher development by Brazilian and Portuguese researchers as highlighted by Paiva et al. (2016). This reinforces the magnitude of internationalization actions in science teacher education.

Internationalization of science degree by international academic mobility

In the studies of this category, we note the actions of internationalization of higher education through the international mobility carried out by CAPES, such as the International Graduate Program (PLI). The objective of this program was to improve the quality of initial teacher training in the areas of Portuguese, Arts, Physical Education, Mathematics, Biology, Physics and Chemistry. This was carried out in sandwich format in partnership with countries such as France and Portugal and enabled the acquisition of double diplomas.

This program contributed in the initial training of chemistry teachers in several aspects, such as the motivational favoring the permanence in the course and incentive to studies, construction of critical and reflective knowledge in various themes, mutual respect and human training, opportunities to exchange professional and intercultural experiences, learning differentiated teaching methodology, among others (Fialho, Santos, & Catão, 2019). However, the authors also report some negative points such as the lack of psychological support, the lack of sharing of experiences, the lack of welcome when returning to Brazil, and the focus on undergraduate courses. This needs to be improved in future international mobility programs.

Another international academic mobility program, considered of great relevance in the process of Internationalization of Higher Education in Brazil was the Sciences without Borders, which took place from 2011 to 2017 and provided international experiences to thousands of students, mainly in the areas of technologies, engineering, and exact sciences. The undergraduate courses had a negligible participation because it was not the focus of this program.

The study by Tonello (2019), addressed the experience resulting from his participation as a biology student in the Paulo Freire Academic Mobility project for teacher training of the

Organization of Ibero-American States for Education, Sciences and Culture (OEI) in collaboration with the Federal University of the Southern Border. The exchange took place at a University of Chile, and allowed to attend courses in the pedagogical area, to observe and practice in schools, to immerse and integrate with the academic community, to improve by participating in events and cultural activities. In other words, international mobility contributed in comprehensive way to the initial training and will help the student's future professional performance.

Although these internationalization actions have been carried out, we verified the low participation of students of teacher education courses in this process, and this number is even lower in the training of teachers in the area of Natural Sciences as emphasized in the work of Paula and Mello (2020). In this sense, programs, projects, and other strategies that promote internationalization in undergraduate degrees should be encouraged and expanded in higher education institutions with government support, to overcome disparities and allow the inclusion of science teachers in this process.

CONCLUSION

Through this study, we identified some evidence of internationalization in science teacher education in Brazil based on bibliographic research. We found eight academic productions in the period from 2017 to 2020 that were analyzed in three categories: internationalization from the perspective of comparative study, internationalization and international cooperation and internationalization of undergraduate science education through academic mobility.

We note the relevance of international cooperation programs and international academic mobility to strengthen and expand internationalization in the initial and continuing education for teachers. CAPES played a fundamental role in the implementation and financing of these actions, which enabled the development and advancement of the internationalization of higher education in Brazil.

Nevertheless, the results show a gap regarding internationalization in the production of science teaching, which indicates the need for more research, programs, and strategies aimed at internationalization in the science teacher education, considering the relevance of this process in pre-service, continued, and professional development.

REFERENCES

Beelen, J., & Jones, E. (2015). The European Higher Education Area. *The European Higher Education Area*, 59–72. Retried from https://doi.org/10.1007/978-3-319-20877-0

Bogdan, R. Biklen, S. (1994). Investigação qualitativa em Educação: Uma introdução à teoria e aos métodos. Portugal: *Porto Editora*.

Bozzi, R. A., Catão, V. (2021). Formação Profissional e Experiências dos professores de Química da UFV na Inclusão Educacional de Surdos. *Revista da Sociedade Brasileira de Ensino de Química*, 2 (1), 1-22.

Cassiani, S. (2018). *Reflexões sobre os efeitos da transnacionalização de currículos e da colonialidade do saber/poder em cooperações internacionais: foco na educação em ciências*. (1), 225–244. Retrieved from https://doi.org/10.1590/1516-731320180010015

Fialho, J. A. R., Santos, M. J. dos, & Catão, V. (2019). Repercussões do Programa das Licenciaturas

Internacionais na formação acadêmica e pessoal de um grupo de licenciados em Química da Universidade Federal de Viçosa (MG). *Educação Química En Punto de Vista*, *3*(1), 1–18.

Franco, M. L. P. B. (2005). Análise de Conteúdo. 2.ed. Brasília: Liber Livro.

Knight, J. (2004). Internationalization Remodeled: Definition, Approaches, and Rationales. *Journal of Studies in International Education*, *8*(1), 5–31. https://doi.org/10.1177/1028315303260832

Leask, B. (2015). A conceptual framework for internationalisation of the curriculum. *Internationalizing the Curriculum*, (September), 26–40.

Moreno-Rodriguez, A. S., & Massena, E. P. (2020). Cooperação Latino-Americana Para a Formação De Professores De Ciências. *Ensaio Pesquisa Em Educação Em Ciências (Belo Horizonte)*, *22*, 1–27. Retried from https://doi.org/10.1590/21172020210143

Nascimento, A. C. D. (2018). *Formação inicial de professores de química na perspectiva da educação inclusiva*. (Dissertação de Mestrado). Retried from (https://bdtd.ibict.br/vufind/Record/USP_c51a27f143b84137fc260406d815fc41).

Paiva, J. C., Morais, C., Rosa, M. P. A., Moreira, L., & Eichler, M. L. (2017). Desenvolvimento profissional e cooperação internacional para professores de química: avaliação da intenção de mudança pedagógica após formação continuada no Porto, Portugal. *Quimica Nova*, *40*(1), 105–112. https://doi.org/10.21577/0100-4042.20160179

Paula, P. C. R. de, & Mello, I. C. de. (2020). Internacionalização Do Ensino Superior No Contexto Das Licenciaturas na Área De Educação Em Ciências. *REAMEC - Rede Amazônica de Educação Em Ciências e Matemática*, *8*(3), 396–414.

Postiglione, Gerard A., Altbach, Philip G. (2013). Profesor: The Key to Internationalization. *International Higher Education*, 73.

Silva-Lopes, B. (2020). Mapping and problematizing the role of portuguese public universities towards science education in the context of international cooperation for development. *Revista Lusofona de Educacao*, *47*(47), 129–143. Retried from https://doi.org/10.24140/issn.1645-7250.rle47.09

Silva Junior, C. R. (2017). *A formação inicial de professores de química e a internacionalização do ensino superior no Brasil*. (Dissertação de Mestrado). Retried from (http://bdtd.ibict.br/vufind/Record/USP_d1e85df95159664e9bdac864e6fc793f)

Stallivieri, L. (2020). International virtual education needs greater support. University World News, 2020.

Stallivieri, L. (2016). Estratégias para Internacionalização do Currículo: do Discurso à Prática. In: Luna, J. M. F. Internacionalização do currículo: Educação. Interculturalidade e cidadania global. Campinas: *Pontes Editores*.

TRAINING STUDENTS TO MASTER THE MATHEMATICAL PREREQUISITES FOR A UNIVERSITY SCIENCE CURRICULUM

Jeanne Parmentier[1], Alain Virouleau[1], Tony Février[1], Jean-Michel Génévaux[2], Martin Riopel[3,4], Marine Moyon[1,4] and Christian Bégin[3]

[1]Institut Villebon – Georges Charpak, Orsay, France

[2]Le Mans University, Le Mans, France

[3]Faculty of Education, University du Québec à Montréal, Canada

[4]Research action chair on educational innovation, University Paris Saclay, Orsay, France

Most science courses at a university level require a prerequisite in mathematics without which students encounter serious difficulties. In order to support students who do not adequately master these concepts, we looked at the possibility of building a mathematics course that focuses on strengthening the prerequisites for the first-year science courses at university.

This program was designed with three goals in mind: (i) to define the key skills which serve as a basis in mathematics and other scientific disciplines, especially in physics (ii) to identify the prior knowledge in mathematics which are the prerequisites for those skills (iii) to strengthen the level of mastery of each skill.

Four strategies were implemented: (i) working in an interdisciplinary team of science teachers to define the targeted skills and support students in their training, (ii) identifying the connections between those skills, (iii) setting up a training course with activities to strengthen assimilation of certain skills targeted by other disciplines as early as possible and (iv) devoting a significant part of the program to prerequisites already seen in middle and high school but not mastered.

This study shows that to best achieve these goals, the sequencing of the content and teaching organisation differ from that of a classic refresher course in mathematics: it does not follow the traditional structural links between the prerequisites. In addition, devoting time to teaching mathematical prerequisites up to middle high school level appears essential.

Keywords: Higher Education, STEM Education, Pedagogical Content Knowledge

INTRODUCTION

It is well known that science students who enter university find it difficult to succeed because they lack a strong mathematical foundation. Struggling with the management and handling of mathematical tools, they fail at comprehending and manipulating the prescribed scientific concepts taught in class.

Conceptual frame

Students need to build on their own prior mathematical knowledge to succeed in mathematics (Faulkner, Hannigan, Fitzmaurice, 2014). The necessary prerequisites to study a concept are not always obvious to a student, even though they are identified by the teacher (Lehtinen, Hannula-Sormunen, McMullen, Gruber, 2017). The latter therefore develops his teaching according to this sequence of prerequisites. For the students who have gaps in their mathematical knowledge, this progression becomes impossible to follow, especially if those gaps are from a high school or even a middle school level.

Prior mathematical knowledge predicts not only success in mathematics, but also in other experimental sciences. Success in physics was even found to be correlated to students' prior success in mathematics and not to their prior success in physics (Meltzer, 2002). Science courses are based on fundamental mathematical concepts that must be perfectly mastered, so that students can focus on higher level disciplinary concepts (Uhden, Karam, Pietrocola & Pospiech, 2012; Blum & Leiß, 2007). However, the standard evaluation does not require learners to have a complete mastery of the content, since a 50% pass rate is usually all it takes to validate a course and move on to the next. Some students entering their first year at university make errors on middle school notions such as the manipulation of fractions, equations of order one or vector additions. To maximize their chances of success in all scientific fields, they must be able to manipulate the prerequisites quickly and without error in order to focus on what is new in their curriculum. Some universities have developed specific programs to sustain mathematical training aimed at different fields (Jackson, 2020).

In addition to the disciplinary content of the course, we know that some learning techniques are more efficient than others (Dunlosky, Rawson, Marsh, Nathan, Willingham, 2013). Spacing (Karpicke, Roediger, 2008) is one of the most efficient way of learning, and interleaved practice improves mathematics learning (Rohrer, Dedrick, Stershic, 2015). These learning techniques are also easy to implement in a curriculum. In order to support students with difficulties, one can decide to embed these techniques directly in the curriculum, to create a context where students naturally apply them without requiring any methodological competencies.

How does one build a program (i.e., content, order) that helps students mastering the necessary prior knowledge in mathematics when they enter a science curriculum in university?

What should be in such a program? How does one decide in which order to teach the different course concepts?

MATERIAL AND METHODS

The Institut Villebon - Georges Charpak is a public interest group that provides a three-year Bachelor program of Science and Technology. At the beginning of each academic year, about thirty-five students are recruited mainly on the basis of their motivation, giving priority to those who might have had disciplinary shortcomings in high school or obstacles to their success in university studies more related to social criteria. Precisely, out of our 105 students: 45% are women, 60% benefit from social grants, and 30% suffer from various disabilies. The program, which received funding from the French National Research Agency in 2012 through the "Initiative D'Excellence en Formations Innovantes" (Initiatives of Excellence in Innovative Training) program, uses active and personalized teaching methods to promote the success of these students. The teaching we designed was spread out over a semester for 35 students, with three sessions per week (two 1.5-hour sessions and one 2-hour session) and provided by two teachers (one maths teacher, one physics teacher), with a total of 60 teaching hours.

Within the framework of this action-research, the design of an upgrading program in mathematics for science at the university entrance is based on informal interactions between mathematics and physics teachers of the undergraduate program. Additionally, an interdisciplinary approach is taken whereby students are taught by both a mathematics and a physics teacher. The mathematical concepts that are necessary in physics and other scientific disciplines are not necessarily the same as those covered in a mathematics course designed to train mathematicians at a university level (Jackson, 2020): for this reason, an optimization of the program was made. The needs of other science courses have been taken into account in deciding the order in which the course concepts are addressed, either at the semester level or at the whole curriculum level.

In order to pinpoint the mathematical tools that have not been mastered, typical errors were identified thanks to previous student cohorts. Informal discussions with high school teachers and a dozen colleagues teaching science at a university level confirmed these observations. In order to measure the extent of students' initial shortcomings as well as their potential progress, a pre-test was administered to students at the beginning of their undergraduate studies. The initial positioning test consists of 3 middle school level questions, 2 sophomore year high school level questions, 2 junior year high school level questions and 10 senior year high school level questions. Here we present two examples of questions: “Calculate the value of the derivative $\frac{df}{dx}$ at x=1 as the function f is defined for all real x by $f(x) = x^2 - 1$” (Question 1), “We randomly choose 3 cards in a 32 cards game, what is the contrary event to "The three cards are kings"? (Question 2)”. The same test with the same questions was also taken twice by students in January (juste after the end of the course) and in June (at the end of the first year).

The resulting program has been organized in blocks (Figure 1). In order to decide of each block’s position, the teachers have worked within a 4 steps process:

1/ Within the disciplinary context (mathematics): Where are the dependencies between each notion ? What are the notions before and after this block? For example, while “elementary geometry” can be done before or after “introduction to functions”, “derivatives” has to be done before “integration”.

2/ Within the interdisciplinary context: Is this notion critical for physics? If it isn’t, on should postpone it as much as possible.

3/ Can one block of notion be postponed in order to create some spaced repetition and interleaved practice?

4/ Are the notions usually perceived as easy or hard by the student? Is it possible to avoid cumulating hard chapters in a row?

RESULTS/DISCUSSION

The initial positioning test shows the need to consolidate middle and high school learning in mathematics for most students. For example, only 54% of students succeed in Question 1 and 50% in Question 2. Other difficulties such a fraction simplification and vector manipulation have not been evaluated in this test but remain present. For example, 20% of the students think that.

Subsequently, 13 objectives were chosen: 2 based on middle school notions, 3 fully covered in high school, 5 deepening elements of high school and 3 novel notions at the undergrad level for the students.

Transfers were made from one year to the next: concepts that were not used by the other scientific disciplines in first year were postponed until second and third year, while those used in first year were integrated as early as possible into the mathematics program.

The resulting program [Figure 1] is divided in 13 blocks and does not resemble a traditional program: it is based on some middle school and high school notions which are traditionally not readdressed at university level. Additionally, it does not follow the usual sequential teaching path between the prerequisites and allows for feedback on blocks of skills in order to improve their acquisition [Figure 2].

The grading is designed to give students the opportunity to work on the evaluated concepts in depth. If a student makes an error in the validation of this block, they can make several attempts until complete success is achieved. The resulting automation of the task and the understanding of the basics, allow the student to adjust their functioning according to the task.

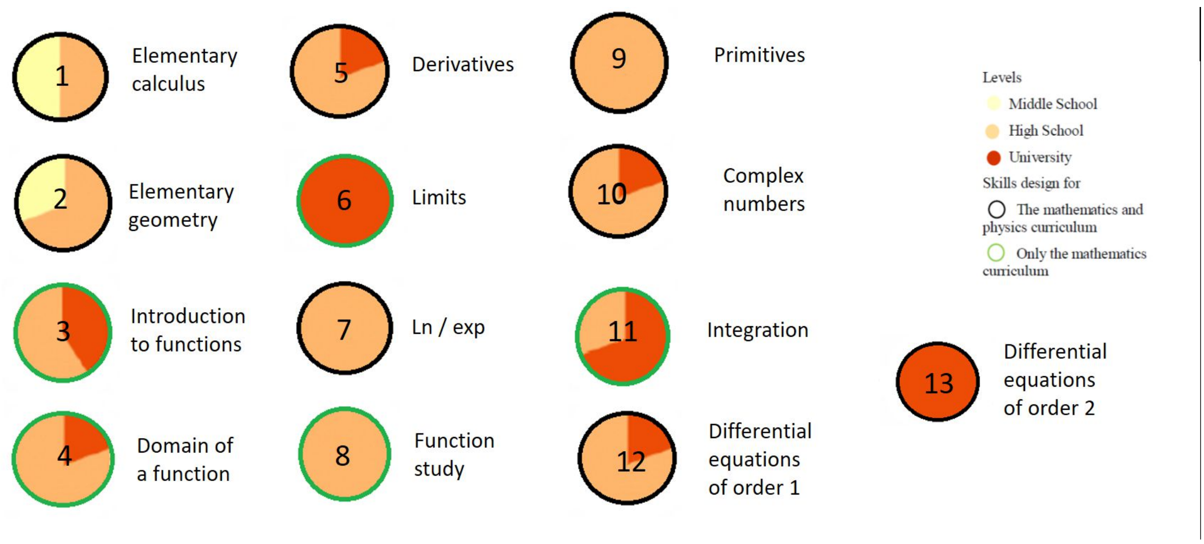


Figure 1. Program of the curriculum. The 13 blocks of skills: the colors indicate the level of the skill levels included in each target (middle school, high school, university level), The skills within a black circle serve as prerequisite for the physics curriculum.

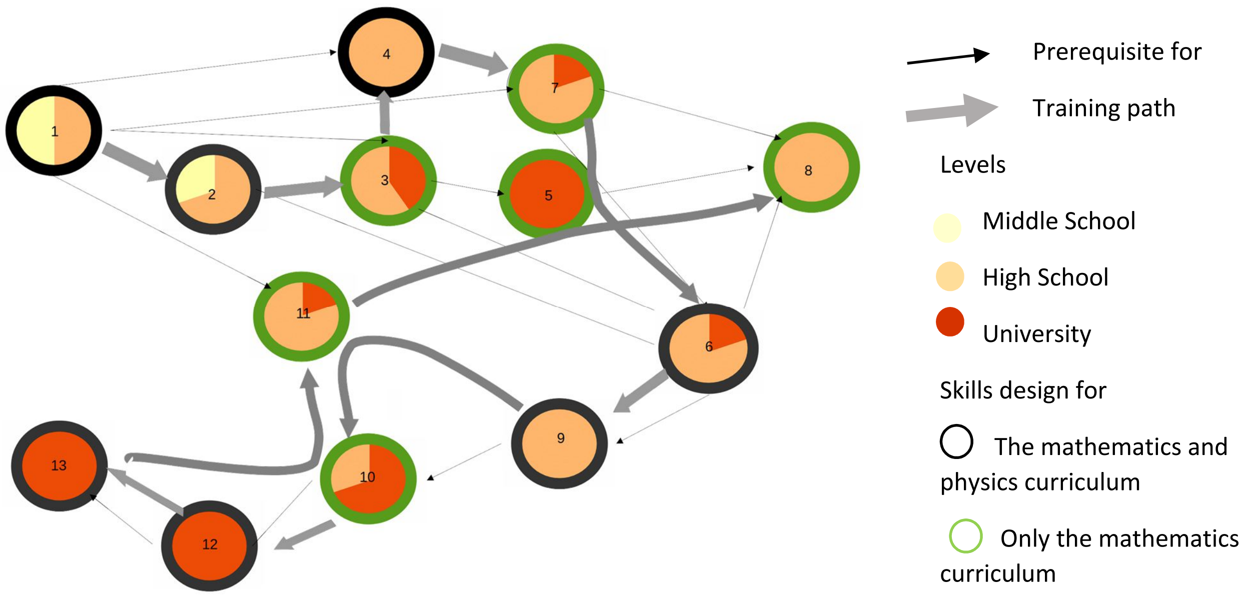


Figure 2. Organisation of the curriculum The 13 blocks of skills: the colors still indicate the level of the skill levels included in each target (middle school, high school, university level), the black thin arrows indicate the prerequisites, the grey thick broken arrow indicates the path of learning offered to the students. The skills within a black circle serve as prerequisite for the physics curriculum.

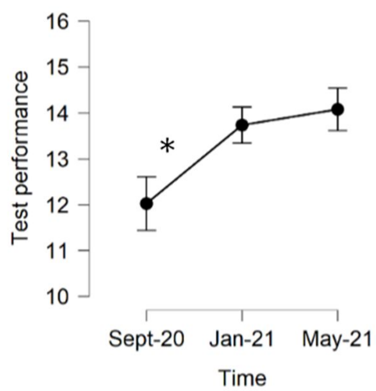


Figure 3. Evolution of the students performance in the positionning test. Significant progress is made during the dedicated semester. No loss 6 months later. No gain either

Regarding the positioning test, we observe a significant increase in the results between the first and the second test taken four months later in January [Figure 3]. This confirms the beneficial effects of the course on student learning.

CONCLUSION

An original refresher course in Mathematics for Science has been developed for students entering university. This course is different from the maths courses generally offered. It is based on our observations of the student's most common shortcomings, includes some notions from the middle school and high school curriculum and insists on the implementation of a great mastery of tools and automation of computational mathematical tasks. Although its effectiveness has not yet been fully tested, preliminary observations show some progress made by students. This program highlights the difficulties of organising the content of remedial courses that we believe is worth continuing to address, both within and outside of our teaching context.

ACKNOWLEGMENTS

We would like to thank all the actors of the Action-Research Chair on Pedagogical Innovation of the University of Paris-Saclay. We would like to thank the referent researchers at UQAM, Prof. Patrice Potvin, Prof. Diane Leduc, Prof. André-Sébastien Aubin & Dr. Geneviève Allaire-Duquette, for accompanying the projects and providing methodological support for the action research. Finally, we would like to thank the 62 teachers involved in the collective reflections, to encourage the improvement and dissemination of our teaching practices. The Chair is financed by the University School of 1st Cycle of the University of Paris-Saclay.

REFERENCES

Blum,W., Leiß, D., (2007). How do Students and Teachers Deal with Modelling Problems? In C. Haines, P. Galbraith, W. Blum, & S. Khan (Eds.), *Mathematical Modelling* (pp. 222–231). Woodhead Publishing. https://doi.org/10.1533/9780857099419.5.221

Dunlosky, J., Rawson, K. A., Marsh, E. J., Nathan, M. J., & Willingham, D. T. (2013). Improving Students' Learning With Effective Learning Techniques Promising Directions From Cognitive and Educational Psychology. Psychological Science in the Public Interest, 14(1), 4-58. https://doi.org/10.1177/1529100612453266

Faulkner, F., Hannigan, A., & Fitzmaurice, O. (2014). The role of prior mathematical experience in predicting mathematics performance in higher education. *International Journal of Mathematical Education in Science and Technology*, 45(5), 648–667. https://doi.org/10.1080/0020739X.2013.868539

Jackson, D. C. (2020). Sustainable multi-disciplinary mathematics support. *International Journal of Mathematical* Education in Science and Technology, 0(0), 1–20. https://doi.org/10.1080/0020739X.2020.1819572

Karpicke, J. D., & Roediger, H. L. (2008). The Critical Importance of Retrieval for Learning. *Science*, *319*(5865), 966-968. https://doi.org/10.1126/science.1152408

Lehtinen, E., Hannula-Sormunen, M., McMullen, J., & Gruber, H. (2017). Cultivating mathematical skills: From drill-and-practice to deliberate practice. *ZDM Mathematics Education* 49(4), 625–636. https://doi.org/10.1007/s11858-017-0856-6

Meltzer, D. E. (2002). The relationship between mathematics preparation and conceptual learning gains in physics: A possible "hidden variable" in diagnostic pretest scores. *American Journal of Physics*, 70(12), 1259–1268. https://doi.org/10.1119/1.1514215

Rohrer, D., Dedrick, R. F., & Stershic, S. (2015). Interleaved practice improves mathematics learning. *Journal of Educational Psychology*, *107*(3), 900-908. https://doi.org/10.1037/edu0000001

Uhden, O., Karam, R., Pietrocola, M., & Pospiech, G. (2012). Modelling Mathematical Reasoning in Physics Education. *Science & Education*, 21(4), 485–506. https://doi.org/10.1007/s11191-011-9396-6

Welsher, A., & Grierson, L. E. M. (2017). Enhancing technical skill learning through interleaved mixed-model observational practice. *Advances in Health Sciences Education: Theory and Practice*, *22*(5), 1201-1211. https://doi.org/10.1007/s10459-017-9759-0

PROMOTION OF SELF-REGULATED LEARNING IN PEER TUTORIALS – INFLUENCE ON UNIVERSITY STUDENTS' USE OF LEARNING STRATEGIES IN BIOLOGY

Svea Isabel Kleinert[1] *and Matthias Wilde*[1]

[1]Bielefeld University, Didactics of Biology, Bielefeld, Germany

The transition to higher education involves institutional and individual challenges for first-year biology students, for example, modified learning environments. Introductory lectures in biology contain a high density of biological topics. With the complexity of biological content, it is assumed that the use of learning strategies plays a key role in studying biology. Therefore, we implemented peer tutoring for a lecture in biology with integrated learning strategy training. Recent research demonstrates the positive effects of tutorials on the students' use of learning skills. However, there are currently no investigations examining peer learning in the context of studying biology. In our study, we conducted tutor-based learning strategy training for first-year biology students to accompany an introductory biology lecture. In a pretest-posttest design, the influence of the implemented tutorial on the strategy use by 200 biology students ($M_{age} = 20.61 \pm 2.97$ *years; 64.5% female) was examined. A pretest and posttest comparison revealed that the tutor-based course fosters the use of almost all learning strategies (cognitive, metacognitive, and resource-based strategies). However, the biology students reported lower values for the scale elaboration in the posttest. In addition, we found significant differences regarding rehearsal, organisational, and time management strategies depending on how often the tutorials were attended. The tutorial with integrated learning strategy training could contribute to the increased use of learning strategies in biology education at the university level. Regarding challenges in the transition to university, peer learning could address higher periods of self-regulated learning.*

Keywords: self-regulated learning, higher education, peer tutorials

INTRODUCTION

The transition to higher education involves institutional and individual challenges for first-year biology students, for example, modified learning environments (Bosse & Trautwein, 2014; Streblow & Schiefele, 2006). As the university learning context could be described as more self-determined and complex, self-regulated learning and learning strategies play an essential role for university academic success (Bellhäuser, Lösch, Winter & Schmitz, 2016), particularly in biology (Binder, Waldeyer & Schmiemann, 2021; Richardson, Abraham & Bond, 2012; Sebesta & Speth, 2017; Shen, Li & Lee, 2018; Waldeyer, Fleischer, Wirth & Leutner, 2019). However, biology students have limited knowledge and ability to use these learning strategies (Sebesta & Speth, 2017). Therefore, peer tutoring settings with integrated learning strategy training have increasingly been implemented in higher education in recent years (Donker, de Boer, Kostons, Dignath van Ewijk & van der Werf, 2014; Hattie, Biggs & Purdie, 1996). According to Dörrenbach and Perels (2016) and Donker et al. (2014), tutorials with integrated learning strategy training could have a positive impact on students' use of learning strategies. However, to our knowledge, few investigations have implemented and examined peer learning settings in the context of studying biology. For this reason, we developed and conducted tutor-based learning strategy training for first-year biology students to accompany an introductory biology lecture.

THEORETICAL BACKGROUND

Transition from school to university

The transition from school to university involves modified institutional and learning conditions, for example, fewer interactive and structured courses (Bosse & Trautwein, 2014), a higher density of learning content (Bosse & Trautwein, 2014; Streblow & Schiefele, 2006), extensive module exams (Streblow & Schiefele, 2006), and less individual feedback (Bosse & Trautwein, 2014; Streblow & Schiefele, 2006). In the context of studying biology, significant amounts of varied learning content were covered in an introductory biology lecture. The high density and complexity of biology subjects often overwhelm biology students. Thus, the excessive demands on students could lead to an increase in university dropouts (Binder, Sandmann, Sures, Friege, Theyssen & Schmiemann, 2019; Loehr, Almarode, Tai & Sadler, 2012). While the university learning context can be described as more self-determined, it is also associated with a higher level of complexity. Therefore, self-regulated learning plays a vital role in studying any subject, particularly biology (Dresel et al., 2015; Shen et al., 2018).

Learning strategies in biology

Zimmerman and Schunk (2011) point out that learning strategies play an essential role in self-regulated learning. According to a classification by den Elzen-Rump, Wirth, and Leutner (2008), learning strategies can be categorised into *cognitive*, *metacognitive*, and *resource-based strategies*. Cognitive learning strategies can be divided into *rehearsal*, *organisational*, and *elaboration* strategies, whereas metacognitive learning strategies consist of *planning*, *monitoring*, and *regulation* strategies (den Elzen-Rump et al., 2008). Resource-based learning strategies include internal and external resources. While internal resources contain *time management*, *effort,* and *motivational strategies*, the *use of literature* and the *arrangement of the learning setting* are considered part of the external resources (den Elzen-Rump et al., 2008).

In the context of biology, various learning strategies could be relevant (Shen et al., 2018). Regarding the high density of biological content in introductory lectures *rehearsal strategies* (e.g. reviewing graded work) (Sebesta & Speth, 2017) could play an essential role. To plan, monitor, and regulate the learning process, *metacognitive learning strategies* such as self-explanations could be implemented (Sebesta & Speth, 2017). Furthermore, *time management strategies* (e.g. timelines, to-do lists) could be relevant for biology students to structure the extensive learning process over the course of the semester (Sebesta & Speth, 2017; Waldeyer et al., 2019). Considering the high complexity of biological topics (cf. Jördens, Asshoff, Kullmann & Hammann, 2016; Parker et al., 2012), *organisational* and *elaboration strategies* such as mind-maps, tables, and diagrams could be relevant (Fiorella & Mayer, 2016; Shen et al., 2018; Stokhof, de Vries, Bastiaens & Martens, 2020). Using these learning strategies could help understand and link different system levels of biological topics (e.g. ecosystems, organisms, organs, cells, cell organelles; Parker et al., 2012).

Learning strategies and learning success

The importance of learning strategies in the university learning context becomes clear in the relationship between learning strategies and academic success (Binder et al., 2021; Fleischer et al., 2019; Richardson et al., 2012). The results of interdisciplinary empirical studies have shown that *rehearsal strategies* predict success in simple learning approaches (e.g. multiple-choice exams), whereas *organisational* and *elaboration strategies* predict the performance in complex learning approaches (Souvignier & Gold, 2004). Furthermore, *effort* and *motivational regulation strategies* play a crucial role in explaining academic success (DeFreyter, Caers, Vigna & Berings, 2012; Kryshko, Fleischer, Waldeyer, Wirth & Leutner, 2020).

Investigations in the science context have indicated that *resource-based strategies* (time management and effort) have a positive effect on university learning success (Binder et al., 2021; Fleischer et al., 2019; Waldeyer et al., 2019). According to Sebesta and Speth (2017), *rehearsal strategies* (e.g. reviewing graded work) predict the academic achievement of biology students (Sebesta & Speth, 2017). In addition, *metacognitive strategies* have a positive impact on academic success (Sebesta & Speth, 2017). As learning strategies could be described as changeable variables, it could be assumed that learning strategy training can foster and support students' use of learning strategies (Sebesta & Speth, 2017).

Peer tutorials with integrated learning strategy training

Investigations regarding the implementation of learning strategies in higher education have become more important in recent years (Donker et al., 2014; Dörrenbach & Perels, 2016; Gutmann, Geiger & Seufert, 2014; Hattie et al., 1996; van der Beek, Bellhäuser, Karlen & Hertel, 2019). Various studies have indicated positive effects of learning strategy training on the students' application of *cognitive* (Donker et al., 2014; Dörrenbach & Perels, 2016; Gutmann et al., 2014; van der Beek et al., 2019), *metacognitive* (Donker et al., 2014; Gutmann et al., 2014), and *resource-based learning strategies* (Donker et al., 2014; Gutmann et al., 2014). In this case, various elements that are particularly effective in the acquisition of learning strategies became apparent. First, a direct link between the learning strategies and subject-specific content proved to be particularly effective (Masui & de Corte, 2005). Second, effective learning strategy training should be integrated into authentic task contexts (Dignath, Büttner & Langfeldt, 2008). In this way, the relevance of different learning strategies for the students can be shown, and the application of these learning strategies can therefore be promoted (Dignath et al., 2008; Masui & de Corte, 2005).

KEY OBJECTIVES

The university learning context requires a higher degree of self-regulation compared to school (Bellhäuser et al., 2016; Shen et al., 2018). Peer learning settings with integrated learning strategy training could provide effective support for students in addressing various challenges in the introductory phase at the university level (Donker et al., 2014; Dürrenbach & Perels, 2016). However, there are currently no studies assessing the influence of peer tutorials with integrated learning strategy training on the students' use of learning strategies in biology. Therefore, our research question can be formulated as follows:

Does peer tutoring with integrated learning strategy training foster biology students' use of learning strategies?

METHOD

Sample

Two hundred first-year biology students (M_{age} = 20.61 ± 2.97 years) participated in the current study, of which 64.5% were female. According to the participation in the tutorials, the biology students were divided into four study groups. The students who did not take part in the tutorial were divided into group I (n = 49). Group II includes biology students who attended the tutorial one to five times (n = 46), and those who participated between six and ten times were assigned to group III (n = 51). Group IV includes biology students who attended most of the tutorial dates (11 to 15 times) (n = 54). No significant differences regarding the sex of the biology students could be found between these four study groups (χ^2(3,178) = 2.29, p = ns).

Test instrument

To investigate the biology students' use of learning strategies, the scales by Baumert, Heyn, and Köller (1992; *Kiel Learning Strategies Inventory*) were applied. The questionnaire consisted of seven subscales and used a five-point rating scale ranging from 0 (*strongly disagree*) to 4 (*strongly agree*). Table 1 below shows the numbers of items with examples for each subscale. To measure the internal consistency of the subscales, Cronbach's alpha was determined. These values were quite satisfactory for the pretest and posttest (Table 1).

Table 1. Sample items, number of subscale items, and Cronbach's alpha (α) values.

Subscale	Number of items	Sample items *When I study biology, …*	Pretest Cronbach's α	Posttest Cronbach's α
Rehearsal	5	… I practice by repeating the material to myself several times.	.82	.78
Organisation	10	… I write brief summaries of the main points.	.84	.79
Elaboration	12	… I try to link the content with previous experiences.	.91	.81
Planning	8	… I write a list of the important content and then learn them.	.78	.76
Monitoring	7	… I observe myself to be sure that I have understood what I have learned correctly.	.79	.74
Regulation	5	… I try to find out what I have not yet understood correctly.	.78	.78
Time management	3	… I determine certain times when I learn.	.64	.61

Test design

We conducted a pretest-posttest design. In the pretest, the students' use of learning strategies was assessed. Afterward, the biology students joined in the introductory lecture. This lecture contained basic biological principles and key concepts, for example in cell biology, biochemistry, and botany. During the semester, the students had also the opportunity to participate in a tutorial guided by biology students in higher semesters. In the posttest at the end of the semester, the scales to investigate the students' use of learning strategies were again applied (Figure 1).

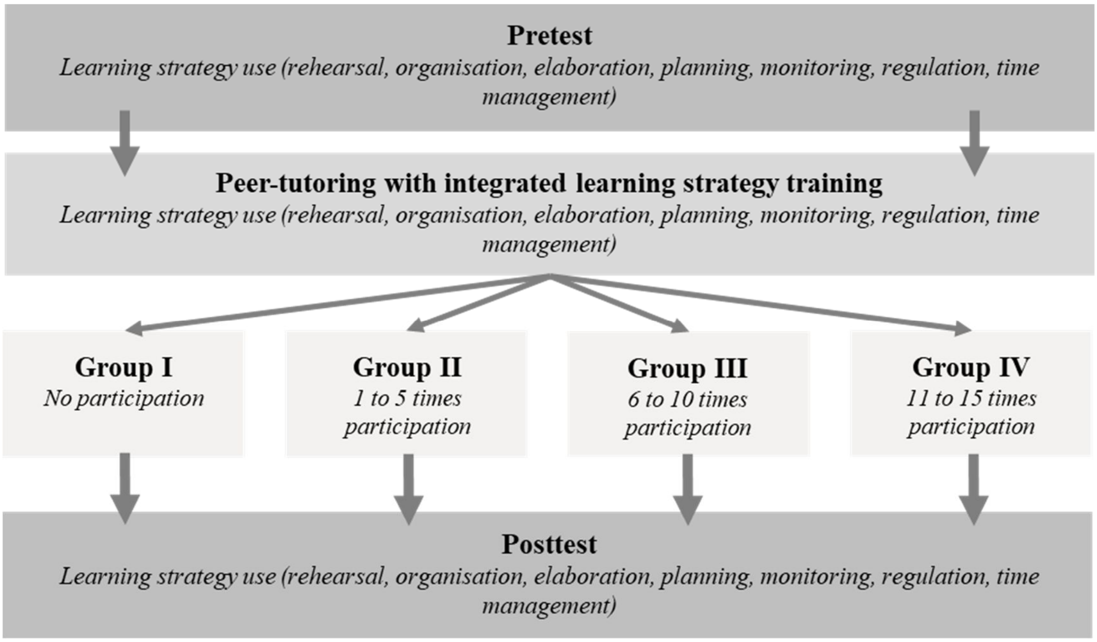


Figure 1. Pretest-posttest design of the current study.

Peer tutoring with an integrated learning strategy training

The weekly tutorials accompanying the introductory lecture lasted about 90 minutes and were guided by biology students in higher semesters. The implemented peer learning setting was divided into three phases.

The first phase of the tutorial included the repetition and presentation of the previous week's lecture content. The biology students were also allowed to address their perceived content-related difficulties and questions. In addition to the repetition of the lecture content, the first-year students were trained in learning strategies in the second phase. The learning strategies discussed in the training were based on the categorisation according to den Elzen-Rump et al. (2008) (*cognitive*, *metacognitive*, and *resource-based strategies*) and were adapted to the special biological topics of the lectures. Organisational strategies (e.g., creating summaries and mind maps) were presented to the biology students as cognitive strategies to use in preparation for the lectures (den Elzen-Rump et al., 2008). Regarding the immediate preparation for an examination, the tutors presented rehearsal strategies in particular (den Elzen-Rump et al., 2008). Metacognitive learning strategies were integrated into the tutorials by addressing planning and monitoring strategies (e.g., self-learning tasks and self-explanations) (den Elzen-Rump et al., 2008). Concerning long- and short-term exam preparation, resource-based strategies (e.g., time management, effort, and motivation management) were also covered in the peer tutorial (den Elzen-Rump et al., 2008). In the final, or practical, third phase, the biology students were permitted to actively work through the learning content in exercises.

RESULTS

In the following section, the results of analysis of variance (ANOVA) with repeated measures are presented.

Cognitive learning strategies

Regarding the students' use of *rehearsal* and *organisational strategies*, we found significant main effects of time with large effect sizes (*rehearsal:* $F(3,196) = 220.95$, $p = .000$, $\eta^2 = .53$; *organisation:* $F(3,196) = 227.84$, $p = .000$, $\eta^2 = .54$). The biology students reported higher values of these learning strategies in the posttest in comparison to the pretest. Furthermore, the ANOVAs with repeated measures revealed significant time *x* group interaction effects with middle effect sizes regarding the use of *rehearsal* and *organisational strategies* (*rehearsal:* $F(3,196) = 3.32$, $p = .021$, $\eta^2 = .05$; *organisation:* $F(3,196) = 2.78$, $p = .034$, $\eta^2 = .05$). Biology students who participated in the tutorial 11 to 15 times (group IV) reported the largest increase in the use of these learning strategies compared to students in groups I – III (Figure 2A and 2B).

Regarding *elaboration strategies*, the ANOVA with repeated measures showed a significant main effect of time with a large effect size ($F(3,196) = 251.70$, $p = .000$, $\eta^2 = .56$). In contrast with the use of rehearsal and organisational strategies, the students showed a lower use of elaboration strategies at the end of the semester (posttest). The ANOVA with repeated measures revealed no significant interaction effect ($F(3,196) = 2.11$, $p =$ ns) (Figure 2C).

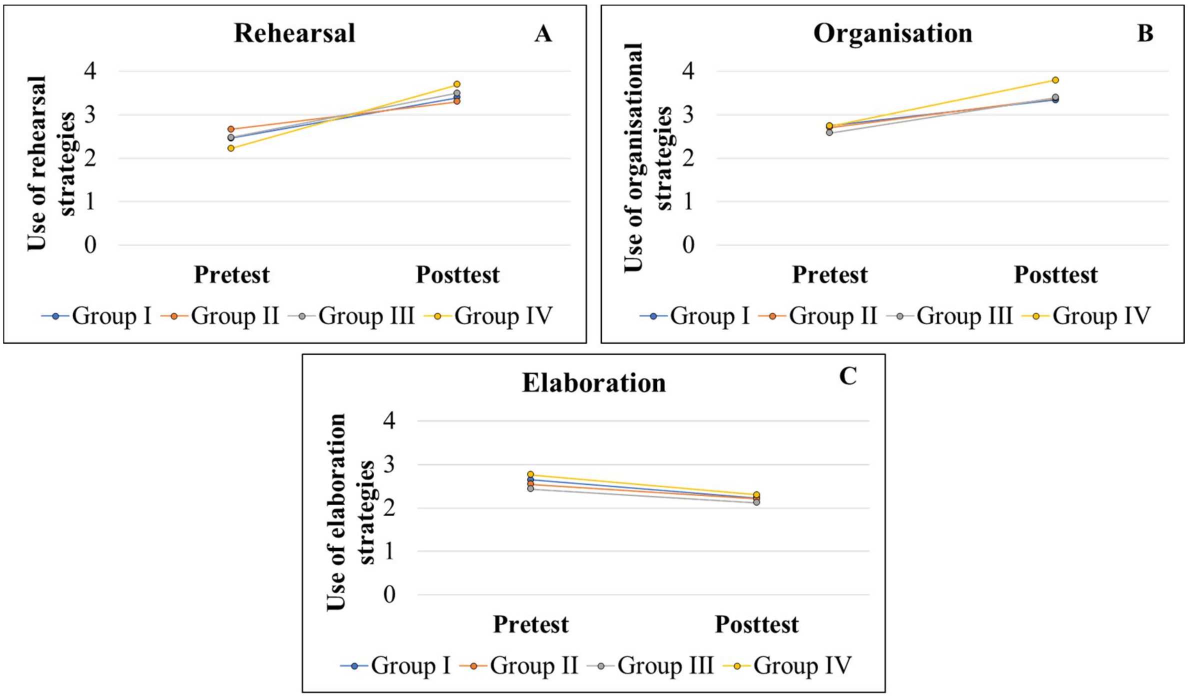


Figure 2. Results of the ANOVAs with repeated measures for *rehearsal* (A), *organisational* (B), and *elaboration* (C) strategies.

Metacognitive learning strategies

Regarding the use of metacognitive learning strategies, the ANOVA with repeated measures showed significant effects of time with large effect sizes. As shown in Figure 3, the biology students' reported a higher application of *planning* ($F(3,196) = 105.49$, $p = .000$, $\eta^2 = .35$), *monitoring* (F(3,196) = 351.78, p = .000, η^2 = .64), *regulation* (F(3,196) = 25.93, p = .000, η^2 = .12) strategies at the end of the semester. However, we found no significant group *x* time interaction effects comparing the use of these learning strategies by the biology students' in group I to IV (*planning*: F(3,196) = 0.34, p = ns; *monitoring*: F(3,196) = 0.91, p = ns; *regulation*: F(3,196) = 1.74, p = ns) (Figure 3A-C).

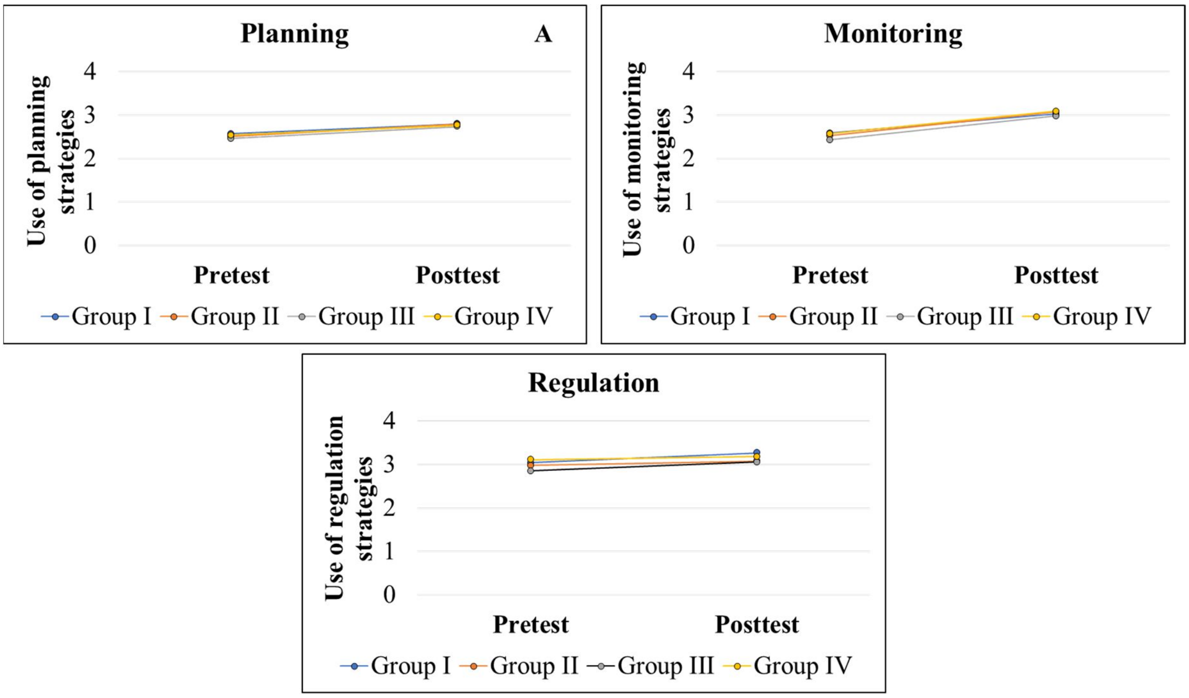


Figure 3. Results of the ANOVAs with repeated measures for *planning* (A), *monitoring* (B), and *regulation* (C) strategies.

Resource-based learning strategies

Regarding biology students' *time management*, the ANOVA with repeated measures revealed a significant main effect of time in a comparison of pretest and posttest with a large effect size (F(3,196) = 321.97, p = .000, η^2 = .62). The biology students reported higher use of time management strategies at the end of the semester. In a comparison of the four study groups, we found significant differences in the scale *time management* (time *x* group interaction effect with a medium effect size: F(3,196) = 23.47, p = .000, η^2 = .11) in favour of the biology students in group IV (Figure 4).

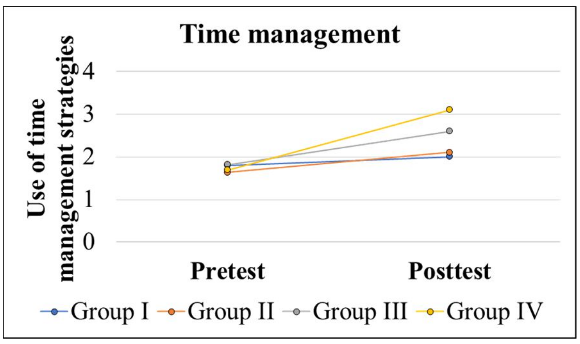


Figure 4. Results of the ANOVA with repeated measures for *time management* strategies.

DISCUSSION AND CONCLUSION

The biology students in all study groups showed higher use of *rehearsal*, *organisational*, *metacognitive*, and *time management strategies* at the end of the semester. The form of examination with a high proportion of reproduction tasks (e.g., multiple-choice) requires the use of rehearsal and organisational strategies (Sebesta & Speth, 2017; Shen et al., 2018; Souvignier & Gold, 2004; Stokhof et al., 2020), which could therefore explain these results. Furthermore, the high density of biological content in the introductory lecture could also explain the higher use of cognitive, metacognitive, and resource-based learning strategies (Richardson et al., 2012; Sebesta & Speth, 2017; Waldeyer et al., 2019). Regarding *elaboration strategies*, the biology students reported lower values in the posttest compared to the pretest. Due to a lack of knowledge about elaboration strategies in the introductory phase in university (Sebesta & Speth, 2017), biology students could overestimate their use of elaboration strategies at the beginning of the semester. The biology students could adequately assess their use of elaboration strategies only by addressing these learning strategies in the learning strategy training. Furthermore, the described type of test, which is largely composed of multiple-choice questions, could explain this trend. The use of elaboration strategies is only slightly required for this exam.

Comparing the four study groups, it becomes clear that regular participation in tutor-based learning strategy training in biological courses could contribute to an increased application of learning strategies. In the context of biology, peer tutoring fosters the use of relevant learning strategies in first-semester examinations (e.g., rehearsal, organisational, and time management strategies). These learning strategy trainings could face the various challenges in transition from school to university, in particular the higher periods of self-regulated learning in biology studies. Thus, our results are in line with previous investigations of Donker et al. (2014), Dörrenbach and Perels (2016), and van der Beek et al. (2019).

A limitation of the current study might be that the various learning strategies were assessed using a questionnaire, which measures the self-reported use of learning strategies. In future studies, qualitative methods such as thinking aloud protocols or learning journals could be implemented to measure students' learning strategies closer to the learning situation (Rogiers, Merchie & Van Keer, 2020). In this case, follow-up studies are needed for further clarification.

Overall, peer tutoring settings could foster the biology students' use of cognitive, metacognitive, and resource-based learning strategies. Therefore, tutorials with integrated learning strategy training could provide useful support for biology students facing various challenges in the transition from school to university.

REFERENCES

Baumert, J., Heyn, S., & Köller, O. (1992). *Das Kieler Lernstrategien-Inventar (KSI)* [Kiel Learning Strategies Inventory]. Kiel: Leibniz-Institut für Pädagogik der Naturwissenschaften.

Bellhäuser, H., Lösch, T., Winter, C., & Schmitz, B. (2016). Applying a web-based training to foster self-regulated learning – Effects of an intervention for large numbers of participants. *Internet and Higher Education, 31*, 87-100. doi: 10.1016/j.iheduc.2016.07.002

Binder, T., Sandmann, A., Sures, B., Friege, G., Theyssen, H., & Schmiemann, P. (2019). Assessing prior knowledge types as predictors of academic achievement in the introductory phase of biology and physics study programmes using logistic regression. *International Journal of STEM Education, 6*, 33. doi: 10.1186/s40594-019-0189-9

Binder, T., Waldeyer, J., & Schmiemann, P. (2021). Studienerfolg von Fachstudierenden im Anfangsstudium der Biologie [Study Success of Biology Science Bachelor Students in the Introductory Phase of University]. *Zeitschrift für Didaktik der Naturwissenschaften, 27*, 73-81. doi: 10.1007/s40573-021-00123-4

Bosse, E., & Trautwein, C. (2014). Individuelle und institutionelle Herausforderungen der Studieneingangsphase [Individual and institutional challenges of the first-year experience]. *Zeitschrift für Hochschulentwicklung, 9*(5), 41-62. doi: 10.3217/zfhe-9-05/03

DeFreyter, T., Caers, R., Vigna, C., & Berings, D. (2012). Unraveling the impact of the Big Five personality traits on academic performance: The moderating and mediating effects of self-efficacy and academic motivation. *Learning and Individual Differences, 22*, 439-448. doi: 10.1016/j.lindif.2012.03.013

den Elzen-Rump, V., Wirth, J., & Leutner, D. (2008). Lernstrategien im Unterrichtsalltag [Learning strategies in everyday teaching]. In S. Kliemann (Eds.), *Schülergerechtes Arbeiten in der Sekundarstufe I: Diagnostizieren und Fördern* (pp. 101-113). Berlin: Cornelsen-Scriptor.

Dignath, C., Büttner, G., & Langfeldt, H. P. (2008). How can primary school students acquire self-regulated learning efficiently? A meta-analysis on interventions that aim at fostering self-regulation. *Educational Research Review, 3*, 101-129. doi: 10.1016/j.edurev.2008.02.003

Donker, A. S., de Boer, H., Kostons, D., Dignath van Ewijk, C. C., & van der Werf, M. C. P. (2014). Effectiveness of learning strategy instruction on academic performance: A meta-analysis. *Educational Research Review, 11*, 1-26. doi: 10.1016/j.edurev.2013.11.002

Dörrenbach, L., & Perels, F. (2016). Self-regulated learning profiles in college students: Their relationship to achievement, personality, and the effectiveness of an intervention to foster self-regulated learning. *Learning and Individual Differences, 51*, 229-241. doi: 10.1016/j.lindif.2016.09.015

Dresel, M., Schmitz, B., Schober, B., Spiel, C., Ziegler, A., Engelschalk, T., Jöstl, G., Klug, J., Roth, A., Wimmer, B., & Steuer, G. (2015). Competencies for successful self-regulated learning in higher education: structural model and indications drawn from expert interviews. *Studies in Higher Education, 40*, 454-470. doi: 10.1080/03075079.2015.1004236

Fiorella, L., & Mayer, R. E. (2016). Eight ways to promote generative learning. *Educational Psychology Review, 28*, 717-741. doi: 10.1007/s10648-015-9348-9

Fleischer, J., Leutner, D., Brand, M., Fischer, H. E., Lang, M., Schmiemann, P., & Sumfleth, E. (2019). Vorhersage des Studienabbruchs in naturwissenschaftlich-technischen Studiengängen [Prediction of drop-out in scientific-technical courses]. *Zeitschrift für Erziehungswissenschaft, 22*, 1077-1097. doi: 10.1007/s11618-019-00909-w

Gutmann, C., Geiger, M., & Seufert, T. (2014). Effekte eines tutorenbasierten Lernstrategietrainings für Studierende [Effects of a tutor-based learning strategy training for students]. *Zeitschrift für Hochschulentwicklung, 9*(1), 1-13. doi: 10.3217/zfhe-9-01/02

Hattie, J., Biggs, J., & Purdie, N. (1996). Effects of learning skills interventions on student learning: A meta-analysis. *Review of Educational Research, 66*, 99-136. doi: 10.3102/00346543066002099

Jördens, J., Asshoff, R., Kullmann, H., & Hammann, M. (2016). Providing vertical coherence in explanations and promoting reasoning across levels of biological organization when teaching evolution. *International Journal of Science Education, 38*, 960-992. doi: 10.1080/09500693.2016.1174790

Kryshko, O., Fleischer, J., Waldeyer, J., Wirth, J., & Leutner, D. (2020). Do motivational regulation strategies contribute to university students' academic success? *Learning and Individual Differences, 82*, 101912. doi: 10.1016/j.lindif.2020.101912

Loehr, J. F., Almarode, J. T., Tai, R. H., & Sadler, P. M. (2012). High school and college biology: a multi-level model of the effects of high school courses on introductory course performance. *Journal of Biological Education, 46*, 165-172. doi: 10.1080/00219266.2011.617767

Masui, C., & De Corte, E. (2005). Learning to reflect and to attribute constructively as basic components of self-regulated learning. *British Journal of Educational Psychology, 75*, 351-372. doi: 10.1348/000709905X25030

Parker, J. M., Anderson, C. W., Heidemann, M., Merrill, J., Merritt, B., Richmond, G., & Urban-Lurain, M. (2012). Exploring undergraduates' understanding of photosynthesis using diagnostic question clusters. *CBE-Life Sciences Education, 11*, 47-57. doi: 10.1187/cbe.11-07-0054

Richardson, M., Abraham, C., & Bond, R. (2012). Psychological correlates of university students' academic performance: a systematic review and meta-analysis. *Psychological Bulletin, 138*, 353-387. doi: 10.1037/a0026838

Rogiers, A., Merchie, E., & Van Keer, H. (2020). What they say is what they do? Comparing task-specific self-reports, think-aloud protocols, and study traces for measuring secondary school students' text-learning strategies. *European Journal of Psychology of Education, 35*, 315-332. doi: 10.1007/s10212-019-00429-5

Sebesta, A. J., & Speth, E. (2017). How should I study for the exam? Self-regulated learning strategies and achievement in introductory biology. *CBE-Life Sciences Education, 16*(2). doi: 10.1187/cbe.16-09-0269

Shen, K. M., Li, T. L., & Lee, M. H. (2018). Learning biology as 'Increase ones' knowledge and understanding': studying Taiwanese high school students' learning strategies in relation to their epistemic views and conceptions of learning in biology. *International Journal of Science Education, 40*, 2137-2157. doi: 10.1080/09500693.2018.1522013

Souvignier, E., & Gold, A. (2004). Lernstrategien und Lernerfolg bei einfachen und komplexen Leistungsanforderungen [Learning strategies and learning achievement in simple and complex approaches of learning]. *Psychologie in Erziehung und Unterricht, 51*, 309-318.

Stokhof, H., de Vries, B., Bastiaens, T., & Martens, R. (2020). Using Mind Maps to Make Student Questioning Effective: Learning Outcomes of a Principle-Based Scenario for Teacher Guidance. *Research in Science Education, 50*, 203-225. doi: 10.1007/s11165-017-9686-3

Streblow, L., & Schiefele, U. (2006). Lernstrategien im Studium [Learning strategies in higher education]. In H. Mandl & H. F. Friedrich (Eds.), *Handbuch Lernstrategien* (pp. 352-364). Göttingen: Hogrefe.

Van der Beek, S., Bellhäuser, H., Karlen, Y., & Hertel, S. (2019). New ways fostering self-regulated learning at university: How effective are web-based courses when compared to regular attendance-based courses? *Zeitschrift für Pädagogische Psychologie, 34*, 117-129. doi: 10.1024/1010-0652/a000254

Waldeyer, J., Fleischer, J., Wirth, J., & Leutner, D. (2019). Validating the resource-management inventory (ReMI): Testing measurement invariance and predicting academic achievement in a sample of first-year university students. *European Journal of Psychological Assessment, 36*, 777-786. doi: 10.1027/1015-5759/a000557

Zimmerman, B. J., & Schunk, D. H. (2011). *Handbook of self-regulation of learning and performance*. New York, NY: Routledge.

TEACHING MOLECULAR ORBITAL THEORY USING A CSCL APPROACH IN AN ENTRY-LEVEL UNIVERSITY COURSE

David Johannes Hauck[1], Andreas Steffen[1], Insa Melle[1]

[1]TU Dortmund University, Dortmund, Germany

In recent years, studies have indicated high dropout rates among chemistry students at university level. Since students enter university with very heterogeneous subject knowledge, a central challenge is to understand complex new topics such as the quantum physical description of chemical bonds. Thus, a digital-collaborative intervention was designed to foster chemistry students' learning of molecular orbital theory during the regular basic chemistry lecture in the first semester.

A first iteration of the intervention was implemented and evaluated in January 2021. There, the students first worked individually with a digital learning environment which consisted of interactive learning videos. In the second part, they worked together in small groups to create concept maps.

This paper presents and discusses the study design and results regarding the students' subject knowledge and personal variables. Beside the students' development across the intervention, a focus is laid on the question of how the design of learning materials in the individual work phase affects the students' subject knowledge growth.

Finally, modifications for a second implementation of the study are derived from the results.

Keywords: CSCL, tertiary education, quantum chemistry, Molecular Orbital theory

INTRODUCTION

The development of scientific knowledge can be understood as a process of building on existing ideas (Heeg et al., 2020; Vygotsky, 1978) through conceptual change (Roschelle, 1992) or conceptual growth (Greeno & van de Sande, 2007). The Computer-Supported Collaborative Learning (CSCL) framework utilises this socio-constructivist approach (Zurita & Nussbaum, 2004). At the product level, collaborative co-construction of new problem-solving knowledge has been shown to be a powerful tool when dealing with complex topics, such as highly interconnected content in STEM subjects (Science, Technology, Engineering and Mathematics, Kyndt et al., 2013; Roschelle & Teasley, 1995; Sung et al., 2017). However, there are still research gaps regarding effective collaboration at the process level (Sung et al., 2017). Particularly, questions have been raised about how individual work and collaboration can influence or even benefit each other (Olsen et al., 2019).

In the project presented, we focus on digital collaborative learning in the tertiary education sector. Here, studies show high dropout rates worldwide, especially in STEM subjects and particularly in mathematics, physics and chemistry (Chen, 2015; Heublein, 2014; Larsen, 2013; OECD, 2020). A study by the European Commission (Eurostat, 2018) identifies difficulties with the content of the university curriculum, along with unfulfilled expectations of studies as central reasons for discontinuing.

In chemistry, students enter the first semester with very different levels of prior knowledge, so that many of them have to revise the basics of the subject (Averbeck et al., 2018; Hailikari & Nevgi, 2010; Tai et al., 2005). Nevertheless, every single one of them also has to deal with challenging topics starting in the first semester. Central among these topics are theories of quantum chemical bonding such as valence bond (VB) and molecular orbital (MO) theory. These theories have proven to be particularly difficult for several reasons (Bouayad et al., 2014; Taber, 2002a, 2002b; Tsaparlis, 1997; Tsaparlis & Papaphotis, 2009): First, quantum physics is particularly abstract by nature. In addition, comprehending these theories requires a profound understanding of mathematical concepts in the fields of linear algebra and stochastics as well as basic knowledge of physics, for example regarding wave mechanics.

Nonetheless, a thorough knowledge of these theories is crucial for the understanding of modern advanced chemistry (Mulliken, 1970) and thus for the long-term academic success of any chemistry student. Following the Atoms First approach (Chitiyo et al., 2018; Zumdahl & Zumdahl, 2016), there are several arguments for teaching quantum chemical bonding theories as part of the introductory lecture. If central concepts are introduced early in the curriculum, it is easier for students to build on them in later semesters.

Research interest and research questions

To ensure that their academic career does not fail at the very beginning, many chemistry students need additional support to overcome the high content barriers at the beginning of their studies. Based on the aforementioned considerations, we have developed an intervention to help students acquiring important quantum physical concepts in molecular orbital theory, using the CSCL framework.

To date, few studies have investigated quantum physical or quantum chemical learning processes from a digital collaborative perspective (Bungum et al., 2015; Partanen, 2018). Hence, our aim is to examine the general learning efficacy of the intervention while addressing research gaps in the field of digitally supported collaborative processes, namely the reciprocal influence of individual and collaborative phases in a co-constructive learning process (Olsen et al., 2019; Sung et al., 2017). Overall, these considerations lead to the following research questions underlying the study:

Q1: What is the influence of person-specific characteristics of academic self-concept, self-efficacy, and gender on students' prior knowledge?

Q2: What effect does the digital collaborative learning unit have on the students' (a) subject knowledge and (b) academic self-concept?

Q3: How does the design of the materials in the individual work phase affect the students' (a) subject knowledge, (b) self-assessment, and assessment by others in a subsequent collaborative work phase?

RESEARCH DESIGN

In order to answer the research questions not only at the product but also at the process level, a mixed methods approach (Tashakkori & Teddlie, 2016) was chosen for the development of the research design. A first iteration of the study was conducted in January 2021 during the regular recitation groups (RG) of the basic chemistry lecture at a German university. *N* = 124 first-semester chemistry students participated in a total of four seminar sessions.

The seminar structure of this first iteration is shown in Figure 1. The intervention took place in two successive phases. In the first phase, students worked individually with a digital learning environment (DLE, Phase 1). In the second phase, students got together to create concept maps in small groups of three to five students each (Concept Mapping Process, CMP, phase 2).

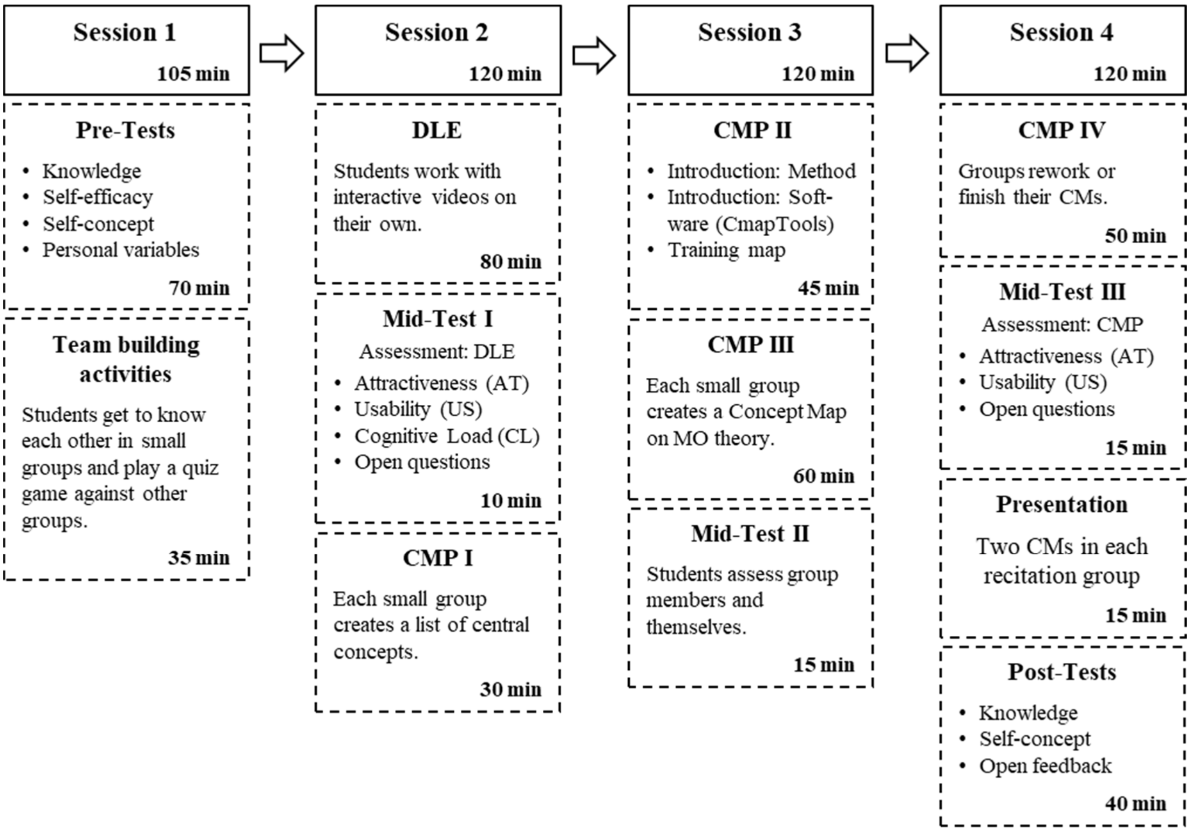


Figure 1. Seminar structure of the January 2021 intervention (CM = Concept Map; CMP = Concept Mapping Process; DLE = Digital Learning Environment).

Phase 1: Digital Learning Environment (DLE)

The DLE consisted of five learning videos. To promote active learning (Brame, 2016), the videos contained interactive elements such as mandatory single-choice questions or supplementary text boxes with additional explanations or information. At the content level, these videos gradually introduced the qualitative Linear Combination of Atomic Orbitals (LCAO) approach of MO theory. These basics were then extended through homo- to heteronuclear compounds. One contentual focus was on the quantum physical foundations of MO theory (Focus 1, F1), another on the application of the theory in the form of the construction and interpretation of MO diagrams (Focus 2, F2).

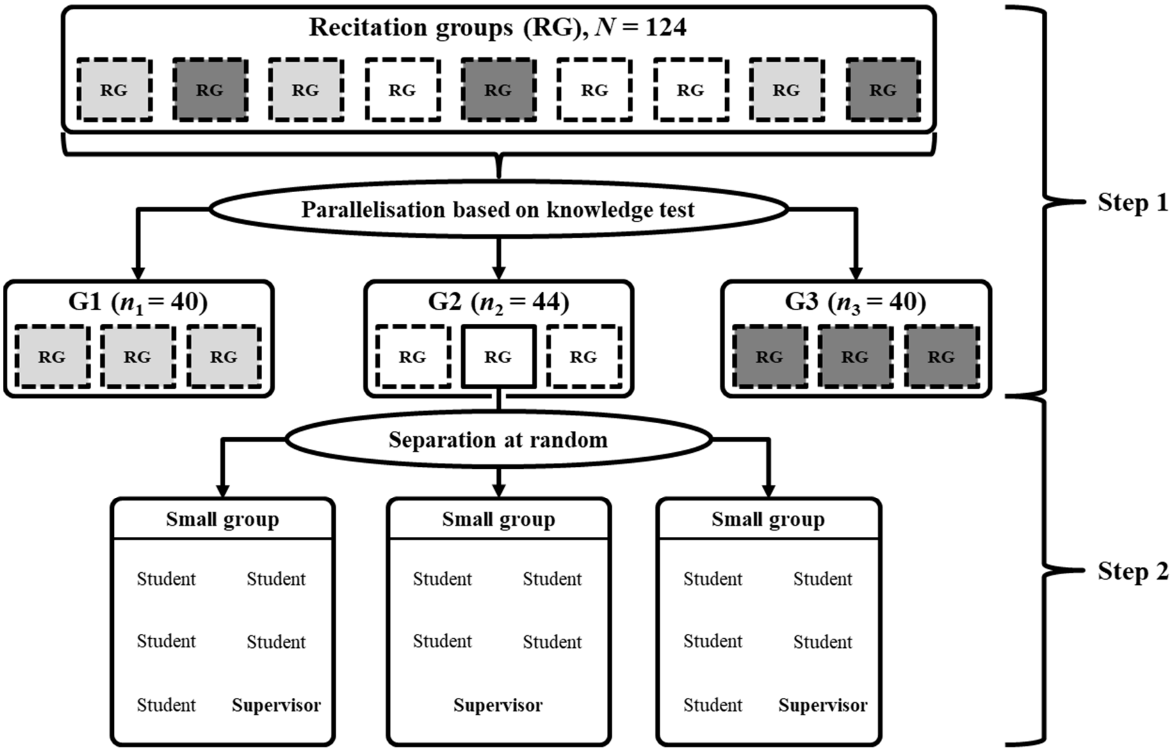


Figure 2. Separation of students from pre-assigned recitation groups (RG) into treatment groups G1-G3 (Step 1) and small groups (Step 2).

As shown in Figure 2, the students were divided into three treatment groups, G1 to G3, to investigate research questions Q2 and Q3. The three groups were parallelised based on the results of the subject knowledge pretest from the first seminar session (cf. Figure 1) in step 1, so that there were no significant differences between any two of the three treatment groups. Throughout the intervention, the students remained in the same recitation groups. In step 2, students within each recitation group were randomly divided into small groups of 3-5 students, each with their individual supervisor.

Table 1 illustrates the three different types of learning videos that students worked with in the three treatment groups: All students in G1 and G2 watched identical videos covering both quantum physical foundations of MO theory (Focus 1, F1) and the construction and interpretation of MO diagrams (Focus 2, F2). Within their respective small groups, the students in G3 were split up: Half of each small group watches videos on F1 only, the other half watches videos on F2 only.

In terms of interactions, the students in group G1 again all work with identical interactive elements. However, the interactive elements differ for students in group G2 and G3. Half of each small group works on interactive tasks for F1, the other half for F2.

Table 1. Explanation of the three different treatment groups G1 to G3 (F1 = Focus 1, quantum physical foundations of MO theory; F2 = Focus 2, application of MO theory).

	G1 ($n_1 = 40$)	G2 ($n_2 = 44$)	G3 ($n_3 = 40$)
Video content	Each group member watches videos containing F1 and F2 ("identical videos").	Each group member watches videos containing F1 and F2 ("identical videos").	Half of the group members watch videos containing F1, the other half watches videos containing F2 ("different videos").
Interactive elements	Each group member works with interactions on F1 and F2 ("identical interactions").	Half of the group members work with interactions on F1, the other half on F2 ("different interactions").	Half of the group members work with interactions on F1, the other half on F2 ("different interactions").

Phase 2: Concept Mapping Process (CMP)

Following the DLE, students worked in small groups to create concept maps together. For this, they compiled, clarified, and discussed a list of about 20 concepts that they considered essential to MO theory. After a short introduction to the method and the software, each small group created a concept map on MO theory using the software '(CmapTools)'. Based on individual formative group feedback, each group was able to revise their maps before some presented their maps to their recitation groups.

Research Instruments

To answer the research questions Q1, Q2a and Q3a related to subject knowledge, we developed a knowledge test which contained 33 closed single choice questions (Knowledge closed, KC, $\alpha_{KC} = .860$) and 7 open-ended questions (Knowledge open, KO, $\alpha_{KO} = .635$). The latter were scored using a low inferential coding manual.

Concerning research questions Q1 and Q2b, students' academic self-concept (Dickhäuser, 2005) and self-perceived self-efficacy (Abele & Spurk, 2009) were assessed by questionnaires.

For each quantitative instrument, Cronbach's α was measured as a means of internal consistency, with overall satisfactory results above the threshold of .700 (Cortina, 1993).

With regard to research question Q3b, we employed additional questionnaires (Brüning & Saum, 2009), in which students assessed both themselves and their group members.

In addition, highly inferential coding manuals are currently being developed for the analysis of the students' concept maps and for screen and audio recordings of the collaborative work phases.

RESULTS

Table 2 shows that the students' prior knowledge correlates significantly with all the personal characteristics surveyed. Weak correlations were measured with self-efficacy and the individual self-concept, medium correlations with the critical, social, and general self-concept. Combining all four subscales of the academic self-concept, a medium correlation with pre-subject knowledge can likewise be observed ($p < .001$, $r_S = .393$). With regard to gender, no significant differences could be measured between the prior knowledge or subject knowledge growth of male and female students.

Table 2. Spearman-correlation r_S of knowledge pre-test results and person-specific variables.

Variable	Example item	p	r_S	α
Self-efficacy	„I know exactly that I can fulfil the requirements set for my chemistry studies if I only want to."	.002	.276	.731
Criterial self-concept	"Compared to the requirements of studying chemistry, I find it easy to learn new things."	< .001	.307	.820
Individual self-concept	"When I look at my development over the time I studied chemistry, I find it easier to learn new things now than before."	.011	.229	.822
Social self-concept	"I think I am more talented for my chemistry studies than my fellow students."	< .001	.432	.872
General self-concept	"Learning new things in chemistry studies is easy for me."	< .001	.313	.756

In the evaluation of the knowledge test (Q2a), five closed ice breaker items were removed from the analysis, as they could be answered correctly by more than 80% of the students in the pretest. For the remaining questions, students in all groups were able to significantly improve their content knowledge during the intervention with a medium effect (result relative to total score: $M_{PRE} = .54$, $M_{POS} = .67$, $p < .001$, Cohen's $d = .597$). The high mean value in the pre-tests can be explained by the fact that the students already start the intervention with prior knowledge, as the topic of MO theory is taught beforehand in the corresponding lecture. Neither in the students' academic self-concept (Q2b) nor the open-ended questions (Q2a) could significant differences be measured over the course of the intervention. The latter can be explained by the fact that four of the seven open-ended knowledge questions asked for definitions of fundamental technical terms such as orbitals, the Pauli exclusion principle or Hund's rules, two of which were already answered correctly by over 75% of the students in the pre-test. The remaining three questions alone may not have been sufficient to measure truly significant effects. In any case, an adjustment of the question format seems necessary here.

Furthermore, a comparison of residuals revealed no significant differences between the three treatment groups G1 to G3 in terms of content knowledge (Q3a).

With regard to students' self- and peer-assessments (Q3b), it was found that group members' assessments were often significantly better than self-assessments, even when students complained about passive group members in the open-ended feedback questions on the CMP. This social desirability bias (Bogner & Landrock, 2016) occurred despite the anonymisation of the responses and can be attributed to the low group size of 3-5 students each, since both the self-feedback and the feedback from the group members were sent to the respective students.

SUMMARY AND OUTLOOK

Subject of this study is to develop and evaluate an intervention that helps students to acquire central quantum chemical concepts of MO theory. As the students participating in the first iteration of the study were able to significantly improve their subject knowledge regarding the closed-ended questions and gave very positive feedback throughout the study, we can conclude that the chosen digital-collaborative approach has proven itself to be viable. Nevertheless, questions remain regarding the collaborative process analysis which need to be addressed with the help of the coding manuals under development. We hope that an in-depth analysis of the concept maps, video and audio recordings will allow us to better understand the learning process, i. e. to find critical leverage points to further facilitate student learning.

Additionally, changes for future iterations of the study can be derived: First, the intervention needs to be extended to 5 dates instead of 4 in order to alleviate the time constraints reported by the students. To facilitate the creation of the concept maps, students will first have to create a glossary.

Secondly, the subject knowledge test will also be revised, since some students entered the study with comparatively high prior knowledge due to their attendance of the lecture in which MO theory was taught. Considering the observed ceiling effects in the subject knowledge test, the too easy items were replaced by more difficult ones. In addition, the open-ended question formats were adjusted to get a better insight into the students' ideas and concepts. In order to better understand the cognitive prerequisites with which students enter the collaborative process and how much they already learn through the learning videos, we will conduct an additional knowledge test directly after the digital learning environment.

To test whether students learn through concept mapping in general or collaborative concept mapping in particular, we will make changes to the design of the comparison groups: While groups G1 (each member of each small group watches the same interactive videos with the same interactive elements) and G3 (members of each group work with different interactive videos) remain, group G2 is replaced by a group in which students create concept maps individually after watching interactive videos in the digital learning environment.

ACKNOWLEGMENTS

We would like to thank all the students who participated in the study and our colleagues from the Department of Inorganic Chemistry for their support in planning and conducting the study.

This project is part of the “Qualitätsoffensive Lehrerbildung”, a joint initiative of the Federal Government and the Länder which aims to improve the quality of teacher training. The programme is funded by the Federal Ministry of Education and Research, funding code 01JA2001. The authors are responsible for the content of this publication.

REFERENCES

Abele, A. E., & Spurk, D. (2009). The longitudinal impact of self-efficacy and career goals on objective and subjective career success. *Journal of Vocational Behavior*, *74*(1), 53–62. https://doi.org/10.1016/j.jvb.2008.10.005

Averbeck, D., Hasselbrink, E., & Sumfleth, E. (2018). Academic achievement of chemistry freshmen - Interrelations between prerequisites and content knowledge acquisition. In O. Finlayson, E. McLoughlin, S. Erduran, & P. Childs (Eds.), *Research, practice and* *collaboration in science education: Proceedings of ESERA 2017* (pp. 2214–2224). Dublin City University.

Bogner, K., & Landrock, U. (2016). *Response Biases in Standardised Surveys.* GESIS - Leibniz Institut für Sozialwissenschaften. https://doi.org/10.15465/gesis-sg_en_016

Bouayad, A., Kaddari, F., Lachkar, M., & Elachqar, A. (2014). Quantum Model of Chemical Bonding: Barriers and Learning Difficulties. *Procedia - Social and Behavioral Sciences*, *116*, 4612–4616. https://doi.org/10.1016/j.sbspro.2014.01.994

Brame, C. J. (2016). Effective Educational Videos: Principles and Guidelines for Maximizing Student Learning from Video Content. *CBE Life Sciences Education*, *15*(4). https://doi.org/10.1187/cbe.16-03-0125

Brüning, L., & Saum, T. (2009). *Erfolgreich unterrichten durch Visualisieren: Grafisches Strukturieren mit Strategien des Kooperativen Lernens* (2. Aufl.). Neue-Dt.-Schule-Verl.-Ges.

Bungum, B., Henriksen, E. K., Angell, C., Tellefsen, C. W., & Bøe, M. V. (2015). ReleQuant – Improving teaching and learning in quantum physics through educational design research. *Nordic Studies in Science Education*, *11*(2), 153–168. https://doi.org/10.5617/nordina.2043

Chen, X. (2015). STEM attrition among high-performing college students: Scope and potential causes. *Journal of Technology and Science Education*, *5*(1), 41–59. https://doi.org/10.3926/jotse.136

Chitiyo, G., Potter, D. W., & Rezsnyak, C. E. (2018). Impact of an Atoms-First Approach on Student Outcomes in a Two-Semester General Chemistry Course. *Journal of Chemical Education*, *95*(10), 1711–1716. https://doi.org/10.1021/acs.jchemed.8b00195

CmapTools. *Cmap Cloud & CmapTools in the Cloud*. https://cmap.ihmc.us/cmap-cloud/

Cortina, J. M. (1993). What Is Coefficient Alpha? An Examination of Theory and Applications. *Journal of Applied Psychology*, *78*(1), 98–104. https://www.semanticscholar.org/paper/What-Is-Coefficient-Alpha-An-Examination-of-Theory-Cortina/2e9accd64f810f9ae12ab35d905e43ecea35b85a

Dickhäuser, O. (2005). A fresh look: testing the internal/external frame of reference model with frame-specific academic self-concepts. *Educational Research*, *47*(3), 279–290. https://doi.org/10.1080/00131880500287211

Eurostat (2018, April 4). Work beats study for 25% of university drop-outs. https://ec.europa.eu/eurostat/de/web/products-eurostat-news/-/DDN-20180404-1

Greeno, J. G., & van de Sande, C. (2007). Perspectival Understanding of Conceptions and Conceptual Growth in Interaction. *Educational Psychologist*, *42*(1), 9–23. https://doi.org/10.1080/00461520709336915

Hailikari, T. K., & Nevgi, A. (2010). How to Diagnose At-risk Students in Chemistry: The case of prior knowledge assessment. *International Journal of Science Education*, *32*(15), 2079–2095. https://doi.org/10.1080/09500690903369654

Heeg, J., Hundertmark, S., & Schanze, S. (2020). The interplay between individual reflection and collaborative learning – seven essential features for designing fruitful classroom practices that develop students' individual conceptions. *Chemistry Education Research and Practice*, *21*(3), 765–788. https://doi.org/10.1039/C9RP00175A

Heublein, U. (2014). Student Drop-out from German Higher Education Institutions. *European Journal of Education*, *49*(4), 497–513. https://doi.org/10.1111/ejed.12097

Kyndt, E., Raes, E., Lismont, B., Timmers, F., Cascallar, E., & Dochy, F. (2013). A meta-analysis of the effects of face-to-face cooperative learning. Do recent studies falsify or verify earlier findings? *Educational Research Review*, *10*, 133–149. https://doi.org/10.1016/j.edurev.2013.02.002

Larsen, M. S. (2013). *Dropout phenomena at universities: what is dropout? Why does dropout occur? What can be done by the universities to prevent or reduce it? A systematic review*. *Clearinghouse - research series: 2013:15*. Danish Clearinghouse for Educational Research.

Mulliken, R. S. (1970). The path to molecular orbital theory. *Pure and Applied Chemistry*, *24*(1), 203–216. https://doi.org/10.1351/pac197024010203

OECD. (2020). *Education at a Glance 2020: OECD Indicators*. OECD. https://doi.org/10.1787/69096873-en

Olsen, J. K., Rummel, N., & Aleven, V. (2019). It is not either or: An initial investigation into combining collaborative and individual learning using an ITS. *International Journal of Computer-Supported Collaborative Learning*, *14*(3), 353–381. https://doi.org/10.1007/s11412-019-09307-0

Partanen, L. (2018). Student-centred active learning approaches to teaching quantum chemistry and spectroscopy: quantitative results from a two-year action research study. *Chemistry Education Research and Practice*, *19*(3), 885–904. https://doi.org/10.1039/C8RP00074C

Roschelle, J. (1992). Learning by Collaborating: Convergent Conceptual Change. *Journal of the Learning Sciences*, *2*(3), 235–276. https://doi.org/10.1207/s15327809jls0203_1

Roschelle, J., & Teasley, S. D. (1995). The Construction of Shared Knowledge in Collaborative Problem Solving. In C. O'Malley (Ed.), *NATO ASI Series, Series F: Vol. 128. Computer Supported Collaborative Learning* (pp. 69–97). Springer. https://doi.org/10.1007/978-3-642-85098-1_5

Sung, Y.-T., Yang, J.-M., & Lee, H.-Y. (2017). The Effects of Mobile-Computer-Supported Collaborative Learning: Meta-Analysis and Critical Synthesis. *Review of Educational Research*, *87*(4), 768–805. https://doi.org/10.3102/0034654317704307

Taber, K. S. (2002a). Compounding quanta: Probing the frontiers of student understanding of molecular orbitals. *Chemistry Education Research and Practice*, *3*(2), 159–173. https://doi.org/10.1039/B2RP90013K

Taber, K. S. (2002b). Conceptualizing quanta: Illuminating the ground state of student understanding of Atomic Orbitals. *Chemistry Education Research and Practice*, *3*(2), 145–158. https://doi.org/10.1039/B2RP90012B

Tai, R. H., Sadler, P. M., & Loehr, J. F. (2005). Factors influencing success in introductory college chemistry. *Journal of Research in Science Teaching*, *42*(9), 987–1012. https://doi.org/10.1002/tea.20082

Tashakkori, A., & Teddlie, C. (2016). *Sage handbook of mixed methods in social & behavioral research* (Second edition (online)). SAGE. https://doi.org/10.4135/9781506335193

Tsaparlis, G. (1997). Atomic orbitals, molecular orbitals and related concepts: Conceptual difficulties among chemistry students. *Research in Science Education*, *27*(2), 271–287. https://doi.org/10.1007/BF02461321

Tsaparlis, G., & Papaphotis, G. (2009). High-school Students' Conceptual Difficulties and Attempts at Conceptual Change: The case of basic quantum chemical concepts. *International Journal of Science Education*, *31*(7), 895–930. https://doi.org/10.1080/09500690801891908

Vygotsky, L. S. (1978). *Mind in Society*. MA: Harvard University Press.

Zumdahl, S. S., & Zumdahl, S. A. (2016). *Chemistry: An atoms first approach* (Second edition). Cengage Learning. http://www.loc.gov/catdir/enhancements/fy1608/2014942489-b.html

Zurita, G., & Nussbaum, M. (2004). Computer supported collaborative learning using wirelessly interconnected handheld computers. *Computers & Education*, *42*(3), 289–314. https://doi.org/10.1016/j.compedu.2003.08.005

FROM SCRATCH TO HATCH: DESIGNING AN EVIDENCE-BASED ENTIRE SEMESTER FOR OPTICAL ENGINEERING STUDENTS

Benjamin Vest[1], Fabienne Bernard[2], Sébastien De Rossi[1], Vincent Josse[1], Matthieu Boffety[1], Julien Villemejane[2], Marine Moyon[3,5], Martin Riopel[4,5], Patrice Potvin[4,5]

[1]Université Paris-Saclay, Institut d'Optique Graduate School, CNRS, Laboratoire Charles Fabry, 91127, Palaiseau, France;

[2] Université Paris-Saclay, Institut d'Optique Graduate School, 91127, Palaiseau, France;

[3] Institut Villebon – Georges Charpak, 91400, Orsay, France;

[4] Université du Québec à Montréal, Montréal, H3C 3P8 Canada;

[5] Université Paris-Saclay, Research Action Chair on Educational Innovation, 91400 Orsay

Evidence-based approaches in teaching and learning provide strategies to empower student learning and long-term retention of knowledge. Such strategies can be implemented at the course level by a single teacher, which then happens at a smaller scale. However, a more powerful approach consists in a coherent integration of neuroeducational principles in the entire structure of a term, involving several courses over several months. This represents an educational change at a higher scale, however facing several risks in its in-practice implementation, such as faculty reluctance and resource insufficiency. We report here on the design of a whole academic term for optical engineering students in dual education at the Bachelor level. It was devised in order to maximize retention effects through a coherent and coordinated use of constructive alignment in course design, active learning activities, metacognition course, and spaced learning. The design process is encompassed within a SoTL (Scholarship of Teaching and Learning) methodology cycle. It involved a total of 12 faculty members, led by a core group of six, trained by educational advisors in neurodidactics, and tasked with the global design, planning and management of the project. At the pre-roll out stage, this work delivered collectively elaborated timetables, syllabus, balanced student workloads, and plans for team teaching and shared educational tasks.

Keywords: Evidence-Based Approaches, Higher Education, STEM Education

INTRODUCTION

Long term retention of knowledge and skills is a good indicator of the efficiency of many teaching activities and pedagogical approaches, common to almost any field at any educational level. It is a solid criterion: indeed, deep learning is often a prerequisite to favor fast and efficient retrieval of previously learned material. Nevertheless, teachers reporting students having trouble with retrieval and retention of learning outcomes is a widespread experience – a serious challenge for students expected to review and master an ever-growing amount of material.

Recent references in the field of evidence-based approaches to teaching and learning, as well as neuroeducation and cognitive psychology, provide recommendations for the design of courses and curricula (Masson, 2020; Latimier, 2019). Course design guides have also been made available, but their in-practice implementation is usually rather poorly documented (Roediger & Pyc, 2012), and noteworthily, is mostly exemplified by smaller scales approaches, at course levels. Besides, neuro educational principles are sparsely used across disciplines and institutions. The pursued research objective was to *develop a research-based academic term at the Institut d'Optique Graduate School (IOGS), a French engineering school specialized in optics & photonics*.

150 new students are enlisted at the IOGS each year. They follow a 3-year track (6 terms), starting at the senior year of undergraduate studies and graduating with a French "Diplôme d'Ingénieur", comparable to a Master of Science in optical engineering (see Figure 1.). The scientific training at IOGS is highly specialized in optics & photonics. It involves a significant fraction of fundamental physics courses, complemented with pratical training during labwork sessions. Around 35% of all students at IOGS decide to complete their MSc in optical engineering with a PhD track.

The current teaching approach at IOGS follows the path most frequently encountered in the French higher-education system: the different courses combine a significant amount of formal lectures delivered to the whole cohort of 150 students, followed by several tutorial sessions in smaller groups, typically between 25 and 30 students. Evaluations consist generally in one final written exam. In their curriculum at IOGS, the students have a heavy experimental labwork sessions program, with weekly reports to handle back.

This study focuses more closely on a cohort of 25 students registered in dual-education. Over the course of these 3 years, students in dual-education spend 50% of their time working in a company, and 50% of their time studying at IOGS following the same courses as other students. Students in dual-ed display no specific differences in their professional future compared to other students of the school, as assessed by post-graduation surveys.

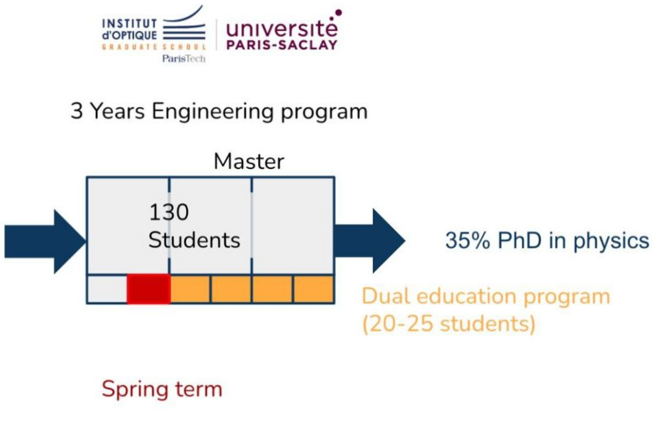


Figure 1. Structure of the Engineering program at IOGS.

This paper reports about the redesign of the second term of a 6 terms academic program for a subset of 25 students among a total of 150 students, it is expected to provide an enhancement of the retention of knowledge acquired during this term over the second and third term of the programme) for these 25 students compared to the remaining 125 students still working with "traditional" lecturing system.

In this paper, we report about the carried design process of the second term of the first year of the engineering track at IOGS, for these dual-ed students. This term is based on seven scientific courses (Polarization, Semiconductor Physics, Electromagnetism, Scientific Computing, Signal processing, Labwork in Optics, Laser Physics). We report about the pedagogically renovated term that resulted from it. The term was conceived in order to maximize long-term retention of knowledge and skills acquired by undergraduate students and expected to provide, in comparison to the traditional "lecturing" system, a solid ground for students to master new material along their entire curricula. This process was based on the implementation of four different strategies, thought as *design rules* for this term: *constructive alignment of courses*, *active learning activities*, *timetable management respectful of spaced learning*, and *metacognition* related activities.

THEORETICAL CONCEPTS

Constructive alignment is a method that aims at building coherence between intended learning outcomes, assessments and learning activities (Biggs & Tang, 2011). It favors deep learning in contrast to surface learning (Ramsden, 2005). It also enables us to quantify and evaluate teaching strategies efficiency.

Active learning practices refer to a variety of activities, such as problem-based approaches, favoring students' cognitive involvement in their own learning process, and enhancing their global performance.

Spaced practice and interleaving are key enablers to long term retention of knowledge and skills, in contrast to massed uninterrupted practice (Latimier, 2019).

Metacognition is about making students aware of their own thought and memorization processes, and to provide strategies to regulate and improve their cognition. Such awareness can improve students' engagement and performances (Sarrasin et al., 2018).

METHODS

The redesign of the whole term involves 13 faculty members of the IOGS, in charge of the 7 scientific courses. We describe here the workforce organization. The *design-based research process* was carried out by a "core" leading team of six teachers (professors), among the whole group of 13 involved in the redesign of the term. For each of the seven scientific courses, a team of two faculty members, including one member of the core team, was formed, and designated in charge of the specific redesign tasks for the course.

Over the course of the project, the core team members interacted with experts in higher-education pedagogy from the Université du Québec à Montréal (UQAM) as participants to an action-research process supervised by the university's department for innovative pedagogy (Research Action Chair on Educational Innovation at Université Paris-Saclay) (See Fig. 2). The design-based process was inspired by the six-step SoTL (*Scholarship of Learning and Teaching*) methodology cycle proposed by Bélisle et al. (2008).

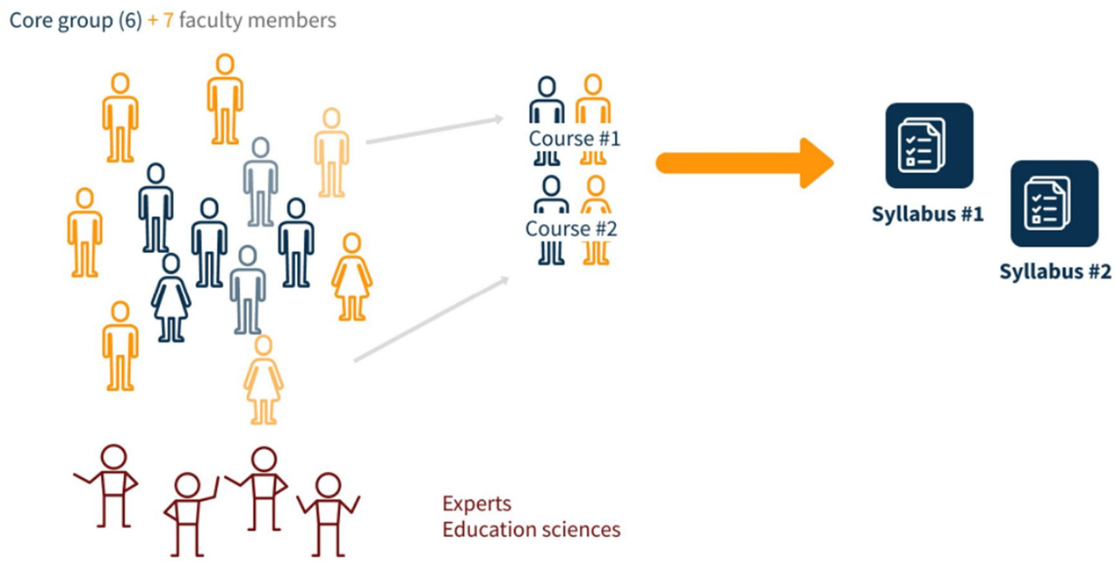


Figure 2. Workforce organization.

The design process involves a group of higher-ed experts training a subset of 6 teachers (the "core" team) among the 13 faculty in charge of the scientific courses taught during the term. Each of course is re-designed by a team of 2 faculty, one of them from the core team.

The project was initiated during a one-week kickoff workshop of the action-research programme in December 2019. The core team got trained on neuro didactic principles and active learning activities by the experts. During this first week, the core team wrote a first draft of the project, clarifying the different design rules to be followed in the redesign process (constructive alignment, spaced learning, metacognition, active learning). Supervised bibliographic works were collectively carried out to further dig the concepts and the methodology to be implemented in the design process.

After this initial training stage, the core team regularly regrouped with the rest of the educational team in order to propose a unified perspective on the project that would allow the coherent implementation of the four pillars of the project, as well as to set a recurring framework for all faculty to continuously progress in the re-design process of their own course (see Transfer/Harmonization step in Table 1) The core team organized a series of meeting for this step, based on feedback discussion of the initial workshop session, discussion of scientific articles and peer instruction during activities, such as the redaction of learning outcomes.

In parallel, the members of the core team took in charge project management tasks. A shared online space was created to store all documents related to the project, such as minutes of meetings, reports, bibliography, timetables, and all digital resources. All resources were accessible to all faculty and experts involved in the project. A shared logbook was also created, keeping track of the different milestones of the project, date after date.

Other resources listed as "tools" were created by the core team, in order to ensure as much as possible the harmonization of practices and the compliance to design rules during the design process. First, a syllabus template was redacted. This template was written to be in adequation with constructive alignment principle. It was provided to all faculty, in order to gather for each of the 7 scientific courses the learning outcomes, the evaluation principles and the planned teaching activities. A catalog of learning activities in an active teaching perspective was also provided. The redacted syllabus were later collected and made available to all teachers. Secondly, a provisional timetable was shared in order to provide an overview of student assessment activities and of the global student workload. Faculty were asked to list their planned activities including the assessment activities and to estimate the time that students will spend of each task. This shared document was used to iteratively design a timetables and tasks to avoid brief work overloads, but also to synchronize the progress of several courses. For example, some notions related to light propagation in matter are present in both the Electromagnetism course and Polarization course learning outcomes. Connections between courses could be established more easily after discussions and interactions based on the respective syllabus and retroplanning of both courses.

Finally, the adequation of the proposed design with all four pillars was discussed during regular consensus meetings or with experts. These meetings serve as validation steps of the design process. The different steps of this elaboration process (adapted from Bélisle et al. (2018) are presented in Table 1 along the four axes of the project.

In practice, this workforce organization was based on regular interactions between higher-education experts and the core team for training and feedback purposes on one hand, and interactions between the core team and other faculty for peer instruction, harmonization of practices and actual implementation of the design rules on the other hand. During the design process, around 30 meetings were set over the course of a year, between December 2019 and the official start of the term in February 2021.Strategies of pre- and post-testing of students along the implementation of the project were designed to monitor the performances of the reference student cohort experiencing the "traditional" lecturing approach of teaching.

Table 1. A summary of methodological steps taken in the design process.

<table>
<tr><th></th><th>Initial training</th><th colspan="2">Transfer/ harmonization</th><th>Tools & methods</th><th>Validation</th></tr>
<tr><td>Constructive alignment</td><td rowspan="3">Training by experts (seminars, coaching during the action research process)
Supervised bibliographic search</td><td rowspan="4">Consensus meetings

Journal clubs

Peer instruction

Feedback about the experience</td><td>N/A</td><td>Work by pairs – syllabus redaction</td><td>Consensus meeting</td></tr>
<tr><td>Active learning</td><td>2-days training</td><td>Activity catalog</td><td>Consensus meeting</td></tr>
<tr><td>Spaced learning / interleaving</td><td>N/A</td><td>Timetables</td><td>Consensus meeting</td></tr>
<tr><td>Metacognition</td><td>Bibliographic search</td><td>N/A</td><td>Feedback from experts and peers</td><td>Feedback from experts and peers</td></tr>
</table>

Several points are to be noted with our methodology. While the scientific perspective of building a system dedicated to the improvement of long-term retention of knowledge is at the heart of the design process, the implementation of a change in pedagogical practices was also strongly motivated by the need to comply to new requirements established by the institution certifying the French Diplôme d'Ingénieur. THis created a concrete sense of urgency, and a need and energy for a curricular change shared among faculty, therefore significantly different from change implementation based on more individual initiatives at the individual course level.

In many aspects, our methodology follows the first steps of the Kotter's change model in the context of engineering education reform by Froyd et al.

RESULTS

The academic term involved seven physics related courses (*Electromagnetism*, *Polarization*, *Semiconductor Physics*, *Laser*, *Scientific computing*, *Signal processing*, *Labwork sessions*) along with metacognition workshops and foreign languages, for a total of 210 hours of in-class presence.

The following paragraphs briefly describe the training formats that were developed at the end of the development cycle:

Spacing/interleaving. Students worked in a dual-education program and shared their presence time between campus and companies. The semester was globally restructured, so that students alternated between three week periods of on-campus work and three week periods of internship time. During campus time, weeks were divided into time slots so that each course was delivered during two 90 minutes time slots on different weekdays (See Fig. 3). This organization results from logistical constraints discussed during consensus meetings, such as teaching or research duties of faculty members.

Figure 3. Timetable and semester schedule.

The spring term of the dual education program lasts 19 weeks, including 9 weeks of full-time internship. Considering the sleep agenda of the students, courses start late in the morning during the weeks of attendance at school.

Constructive alignment. Teachers worked similarly to a think-pair-share scheme, working in pairs of disciplines to share experience and personal research on the topic. All teachers were asked to fill in a descriptive form of their strategy, detailing their intended learning outcomes, assessments tasks and learning activities. Validation of the forms were carried out during consensus meetings and formed a basis for syllabus. This work enabled also to evaluate the students' workload during the semester, to envision synchronization of courses between disciplines and a better repartition of intended learning outcomes (avoiding unnecessary repetition across different courses, sharing same vocabulary, notations, identifying student misconceptions).

Active learning. All courses have introduced active learning activities as part of their teaching strategy. For example, the Electromagnetism course was delivered in a flipped-classroom format. The Laser physics and Semiconductor physics courses introduced case studies and problem based learning activities, etc. Some of the activities also included formal or informal assessments, providing opportunities to give students feedback more regularly along the term.

Metacognition. Weekly metacognition workshops were part of the students' schedule. Sessions focused on a description of cognitive and brain processes and their connection to learning practices, as well as their perceived effectiveness. (See Fig 4.)

Figure 4. Themes addressed during the metacognition workshops.

While not explicitly put in the initial objectives of the projects, additional dimensions arose during the design process: implementation of regular assessment and self-assessment tasks to the students (and related discussion on the repartition of in-class and at-home workload of the students); the time of the first lesson in the morning was set at 9:30 am, 30 minutes later than usual, as an effort to take into account the students sleep time.

This new design was implemented for the first time in February 2021 for a first cohort of students. Evaluation of the courses by the students was carried out to get feedback from the student's perspective through an online survey at the end of the term. A vast majority of students showed highly enthusiastic and positive about the general perspective of being part of an educational change strategy, and expressed a significant interest and satisfaction with the new teaching strategies, in contrast with their previous experience with traditional lecturing. Interestingly, as this cohort was affected by the pandemic, remote teaching was also introduced, but incorporating remote active learning strategies. While students of the reference cohort in contact with "remote traditional lecturing" reported a very low satisfaction rate, we observed a marked contrast with the studied cohort, displaying a satisfaction rate for the "remote active learning" activities in par with physical class.

In parallel assessment of student performances revealed no specific difference, neither positive or negative between students from the reference cohort and students under the revised term. A series of tests are introduced for the rest of their curriculum in order to evaluate the possible effect of this new term on long-term retention.

CONCLUSION

In this paper, we reported about the design of a whole academic term trying to maximize the outputs of a coherent use of spaced practice and interleaving, course design based on constructive alignment, use of active learning practices and awareness of students to metacognition aspects. This project was led at an intermediate scale, involving 13 teachers leading 7 courses, overcoming limitations of a single course implementation of similar strategies. The design was carried out using a team organization based on a core group of six teachers in charge of the global project management, interacting with experts and getting trained on the key aspects of the envisioned pedagogical practices, and then working with the rest of the group to share experience, provide resources and tools and validate elaboration steps during consensus meetings. The impact of the semester on the long term retention of knowledge and skills by students will be monitored during the rest of their time on campus, thanks to a pre-test post-test strategy for which the results will be used to adjust the educational change strategy.

ACKNOWLEDGMENTS

The authors want to thank Jeanne Parmentier, Isabelle Demachy and the team of the "Centre d'Expérimentation Pédagogique" of the Université Paris-Saclay for fruitful discussions and their constant support.

REFERENCES

Bélisle, M., Lison, C., & Bédard, D. (2016). Accompagner le Scholarship of teaching and learning. Comment développer le conseil pédagogique dans l'enseignement supérieur, 75-90.

Biggs, J. B., & Tang, C. S. (2011). *Teaching for quality learning at university: What the student does* (4. ed). McGraw-Hill, Society for Research into Higher Education & Open University Press.

Froyd, J. E., Penberthy, D., & Watson, K. L. (2000). *Good educational experiments are not necessarily good change processes.* Frontiers in Education Conference 2000 FIE 2000 30th

Annual (Vol. 1, p. F1G/1-F1G/6 vol.1).

Kotter, J. (1996). *Leading Change.* Harvard Business School Press, Boston.

Latimier, A. (2019). *Optimisation de l'apprentissage par récupération en mémoire pour promouvoir la rétention à long terme de nouvelles connaissances. [Optimizing the use of retrieval practice to enhance long term retention of new knowledge]*. PhD Thesis, retrieved from http://www.theses.fr/s175067

Masson, S. (2020). *Activer ses neurones : Pour mieux apprendre et enseigner. [Activate your neurons: To learn and teach better]*. Paris: Odile Jacob.

Ramsden, P. (2005) *The Context of Learning in Academic Departments* in: Marton, F., Hounsell, D. and Entwistle, N., (eds.) The Experience of Learning: Implications for teaching and studying in higher education. 3rd (Internet) edition. Edinburgh: University of Edinburgh, Centre for Teaching, Learning and Assessment. pp. 198-216.

Roediger, H. L., & Pyc, M. A. (2012). *Inexpensive techniques to improve education: Applying cognitive psychology to enhance educational practice.* Journal of Applied Research in Memory and Cognition, 1(4), 242–248.

Sarrasin, J. B., Nenciovici, L., Foisy, L.-M. B., Allaire-Duquette, G., Riopel, M., & Masson, S. (2018). *Effects of teaching the concept of neuroplasticity to induce a growth mindset on motivation, achievement, and brain activity: A meta-analysis.* Trends in Neuroscience and Education, 12, 22–31.

TEACHING PHOTOELECTRIC EFFECT WITH PHOTOVOLTAIC CELLS USE IN THE PHYSICS LABORATORY

Mari Aurora Favero Reis[1] and Agostinho Serrano[2]

[1]Universidade do Contestado, Concórdia (SC), Brasil.

[2]Universidade Luterana do Brasil, Canoas (RS), Brasil

The photoelectric effect is an important phenomenon in the teaching of Modern and Contemporary Physics in Engineering, as it allows contextualizing science teaching in technological applications associated with the emission and transformation of light. Our research question is: "Can photovoltaic cells be used in the physics lab to teach engineering students the photoelectric effect?" The literature suggests photovoltaic technology, driven by the STEM movement (Science, Technology, Engineering, Mathematics) to teach the photoelectric effect in Engineering. An experiment was structured using a photovoltaic panel for didactic use at night, with artificial lighting, using different types of lamps. We applied the experiment in the classroom using pre and post-tests and an interview. The results of this experiment showed that after using photovoltaic cells it was possible to verify that students correctly correlate the photoelectric effect with the frequency of incident radiation and no longer with the intensity of light. The application of didactic methodology within the scope of Engineering courses also contributed to the integration of teaching, research, and extension in the community, in addition to allowing the student to reflect on the social changes resulting from scientific and technological evolution can contribute to sustainability and changes social and environmental.

Keywords: Photoelectric effect, photovoltaic technology, STEM

INTRODUCTION

By using the photoelectric effect when teaching science in Engineering courses, it is possible to contextualize the teaching of Physics in technological applications. The teacher can associate the concept of emission and transformation of light with different technological applications such as sensors, diodes, lasers, semiconductors, especially when it comes to artificial lighting and sustainability electrical. Bibliographic research has shown that the use of a didactic experiment in photoelectric effects is limited and the experiments are complex for use in education (Reis & Serrano, 2017). Klassen, Niaz, Metz, McMillan, & Dietrich (2012) point out that the experimental work on the photoelectric effect started to be used after the development of solid-state electronic technology, around 1960, with the overcoming of technical difficulties.

Among the applications, photovoltaic technology was boosted due to the negotiations agreed in the Kyoto protocol (2008 to 2012), for reducing greenhouse gases emission (Sark, 2007). With the use of photovoltaic cells in physics classes, it is possible to explore, in a contextualized way, the principle of the photoelectric effect in the transformation of light into electric current. It also makes it possible to explore with students the use of current, voltage (IV), generation power (Boitier & Cressault, 2011; Morgan et al., 1994), and quantum efficiency in the transformation of light (Kraftmakher, 2008).

Especially with engineering students, the technology was applied to evaluate the efficiency of the silicon cell in converting light into energy when exposed to dust in the desert (Molki, 2010). Subsequently, Dark (2011) presents the photovoltaic modules in STEM (Science, Technology, Engineering, Mathematics) courses, to develop quantitative analysis and scientific communication skills, in addition to increasing students' interest in Physics. By observing that the current and voltage decrease as the temperature in the silicon photovoltaic cells increases, using mathematical abilities when performing data collection and analysis, considering uncertainties or in the conversion of units when presenting in scientific articles, it is possible to awaken interest in a career in science and engineering. This application can also contribute to the teaching of silicon-based electronics (Gfroerer, 2013), semiconductor operation (Jenkins, 2005). In these materials, the photoelectric effect on silicon cells behaves as an insulator until there is an external energy source, such as sunlight, capable of 'boosting' its electrons from the valence band to the conduction band, making current-carriers (Richards & Etkina, 2013).

Therefore, this work sought to answer the research question: "How can photovoltaic cells be used in a physics laboratory to teach engineering students the photoelectric effect?"

ASSEMBLY, VALIDATION AND EXECUTION OF THE EXPERIMENT

Assembly of the experiment

The university's Physics laboratory has an experimental kit with a 5Watt photovoltaic panel, with 72 photovoltaic cells, which allows it to be used during the day, with solar lighting, or at night, with two points of artificial light (Figure 1). The teaching set has a current converter with charge accumulator, coupled to measuring equipment (Voltmeter and Ammeter) and on the panel, allowing the verification of voltage, current, and resistance.

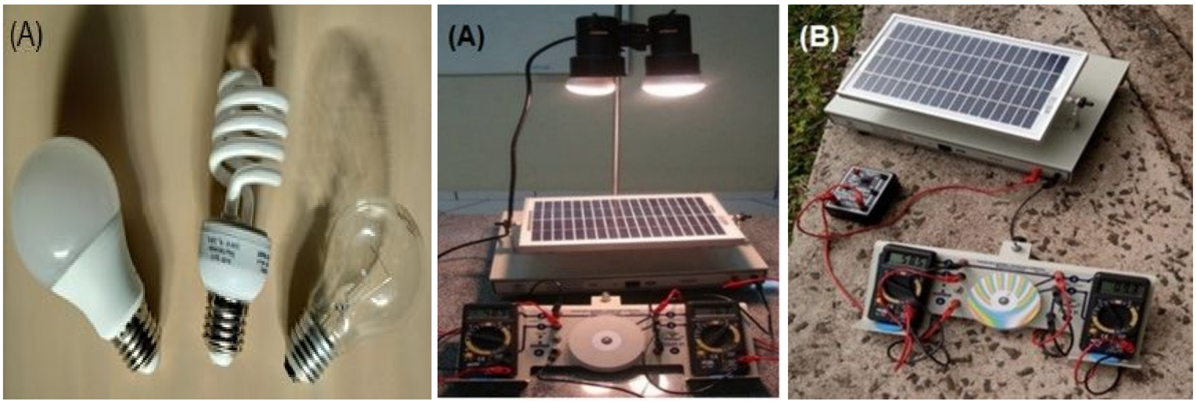


Figure 35. Assembly of the experiment: photovoltaic with artificial lighting (A) and solar (B).

To carry out this experiment, a pilot experiment was created and applied in 2016, with 31 students of two classes ($T_A = 16$ and $T_B = 15$) and in 2017 the definitive experiment, with 24 students. Both experiments were carried out in Physics class 3 for students of Civil Engineering and Environmental and Sanitary Engineering.

The validation of the pilot experiment was carried out at night, with four activities: (i) transforming the light from incandescent lamps (60W) into current; (ii) transforming light from fluorescent lamps (15W) into current; (iii) transforming the light of LED lamps (8.5W) into current and, in the latter, (iv) the activity of evaluating the efficiency in converting light into electricity. All lamps emitted white light, with a luminous intensity of approximately 800 $lm.m^{-2}$ (Figure 2A). In the activities, the students evaluated the current, the voltage, and for these values, the power and resistance calculations. Subsequently, they calculated the efficiency (η) in transforming light into electrical energy. In carrying out the activities, in the validation, the students used a laboratory script, pre-test, and post-test (as used in the definitive experiment), to guide them in the learning process.

The results of the pilot experiment in the students' learning were not satisfactory, since when answering a post-test, the students provided incorrect answers when they demonstrated the alternative conception that infrared radiation (heat) was responsible for the production of energy, justifying that incandescent light generated more current. This conception is mistaken since this lamp presents a peak of initial production and as the silicon cells are heated, the current decreases significantly, increasing the electrical resistance, as shown in the literature (Dark, 2011). This result does not occur with the others light sources (fluorescent and LED), presenting a stable current.

Methodology in the definitive experiment in the Physics laboratory

To solve this problem presented earlier in the pilot experiment, the experiment was changed, adding lamps with the longest wavelength (red) and the shortest wavelength (blue) light. Thus, after carrying out experiments using white light from LEDs, fluorescent and incandescent (Figure 2, A), the students proved that they had replaced the white light bulbs with colored light bulbs (Figure 2, B). In this way, they could assess the influence of light frequency on current and voltage, observing the measurement instruments (ammeter and voltmeter).

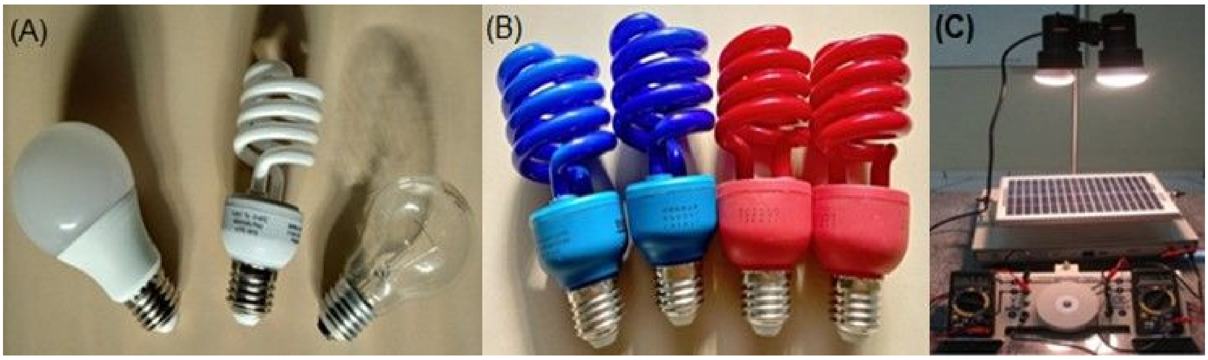


Figure 36. Technologies: The lamps used in the pilot and final experiment (A); Lamps added in the final experiment (B); Setting up the experiment (C).

Interventions with students took place after approval by the Human Research Ethics Committee (Number 2,253,630). Data were collected in the definitive experiment using interventions (Reis, 2019): pre-test, post-test, script for activities in a real laboratory and recorded interviews. The methodological foundations that guide the research is predominantly qualitative, of the case study type (Erickson, 1986).

The script used by the students during the laboratory activity (Reis & Serrano, 2019), was built using the P.O.E. (Predict-Observe-Explain) methodology, similar to that used in a computational experiment (Reis et al., 2021; Tao & Gunstone, 1999), and actually inspired in the Demonstrate-Observe-Explain used by teachers when demonstrating experiments during the classroom. In the visualization phase, after a brief introduction, students should describe their previous concepts of how photovoltaic technology works. In the experimentation phase, they observed the transformation of artificial light into electricity, utilizing LED, fluorescent and incandescent lamps, and recorded current, voltage, power calculation, and resistance to current flow. Then the teacher replaces the white light bulbs with colored light bulbs (red and then blue) and the students repeat the records and calculations (Figure 3).

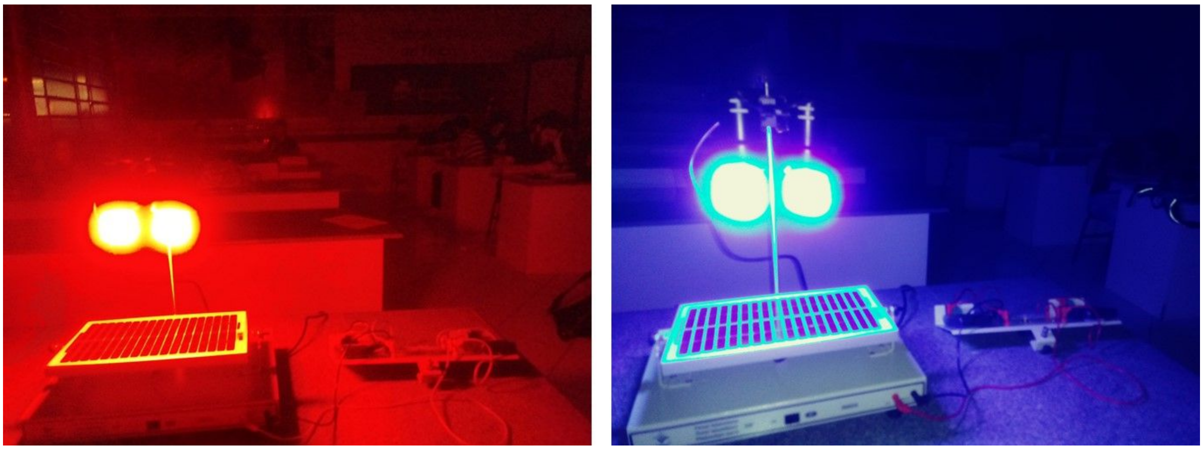


Figure 37. Activities Using Red Light, Low Frequency and Blue Light, High Frequency.

And, in the explanation stage, students can reflect on the results, noting that the current is influenced by the transformation of light into energy. In lamps with resistance, electrical power decreases with increasing temperature, as demonstrated by previous studies (Boitier & Cressault, 2011; Dark, 2011; Morgan et al., 1994). In these steps, they are motivated to reflect on the role of the frequency of emitted light in the transformation of light into energy.

EXPERIMENTAL RESULTS AND DISCUSSIONS

The comparative analysis between the instruments applied at the beginning of the activities (Pre-test) and after the activities (Post-test) showed a significant evolution in the students' answers, for all the investigated concepts. In the interview, it was asked in the interview, it was asked “if the frequency of light changes, what happens to the current and the emission of photons?”. Student E4, for example, who answers in the pre-test that he does not know, says in the post-test "change the current". When justifying, he mentions the "calculations" of the current and voltage on the power generated by the photovoltaic plates when the lamps are white or colored (blue and red), referring to the mathematical modeling of the data provided in the guide (Reis & Serrano, 2019) activities used in the experiment laboratory. In the first columns, the data observed in the lamps, the light intensity (lm) and the measurements (voltage and current) were registered. Then the students performed the resistance and power (W) calculations (Figure 4).

CARACTERÍSTICAS DA LÂMPADA	MEDIR			CALCULAR	
	Intensidade luminosa (lm)	v (V)	i (A)	R (Ω)	P (W)
Vermelha - 14W	180	2,8	0,01	270	$2,7 \times 10^{8}$
Branca 14 W	254	31,5	2,22	14,29	$8,29 \times 10^{-9}$
Vermelha 26 W	1846	8,05	0,6	14,16	$5,1 \times 10^{-6}$
Azul 26 W	1846	18	1,3	13,84	$2,34 \times 10^{5}$

Figure 38. Calculation mentioned by E4 when relating the frequency of light and electrical current. Note: Measurements: light intensity (lm), voltage (V) and current (A). Calculations: resistance (Ω) and power (W).

To the same question, another student answers: "Because, if I'm not mistaken, the frequency of [...], the frequency of each color is different from one another and therefore, it doesn't increase from nothing and as we observe [...] on multimeters [...] it increased little by little" (E2). In non-verbal language (Figure 5), the student makes an indicative gesture with his hand towards the experimental physics laboratory (Figure 5A) and when he relates the current and voltage variables in the photoelectric effect, he represents the device (multimeter) used in the measurements (Figure 5B).

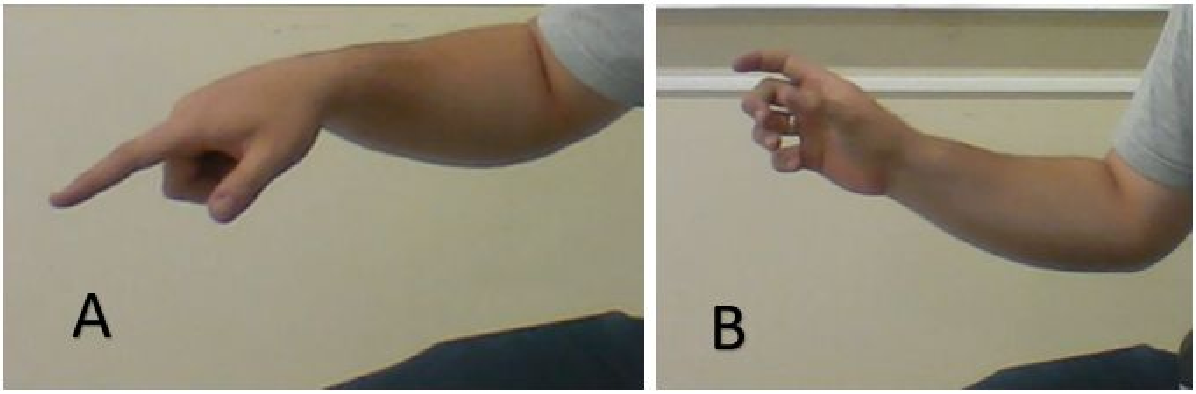


Figure 39. Gestures demonstrated by student E2 during the interview, which show the influence of the experiment on learning concepts: (A) points to the laboratory, (B) makes gestures for measuring current talk.

In the interview, students were asked: If you had to explain to one person what the photoelectric effect is, what would you say?" Student E5 researched the use of thin silicon films and flexible photovoltaics in that period (Schönell et al., 2020), responds:

> Laughter [...] I had to explain to my 5-year-old girl: A beam of light, depending on its color, has a certain length and therefore a certain frequency, because it is faster [...] and oscillates several times in a smaller space it [...] ends up hitting the electron [...] that is on the plate or film, depending on what you are using, hits the electron thus giving energy to the electron and moving to another band of the plate, generating current. (E5)

Other students answered the same question in the same line of thinking, explaining the transformation of light microscopically:

> I would say it is the transformation of light into energy. (E6; E9)

> When there is an incidence of light in a certain material, these electrons that are in the material are energized [...] and there is an exchange of electrons, and this movement is what we call electrical energy. (E14).

The results of this analysis showed that after use red and blue light it was possible to verify that students correctly correlate the photoelectric effect to the frequency of incident radiation and not to the intensity of light. And the testimonies of the students at the end of the interview, when asked “What is your opinion in relation to studying with a teaching unit where we work with different methodologies, containing different practical and theoretical activities?”. The students answered:

> (...) sunlight, which is luminosity, what generates energy is the ultraviolet, which is what you do not see. What you do not see generates energy. (...) how the different types of materials react, the stimuli, which was computational and the most interesting was when I understood how photovoltaic cells worked. (E5).
>
> (...) Because the incandescent lamp I thought it produced more energy and, in the calculations, we saw that it was the opposite. That is not quite the case (E13).
>
> Because when you change the lamp, the blue lamp, I think, increases the production of photons, right? That's right. (E17)

Therefore, photovoltaic technology, used with artificial lighting, proved to be effective as a context application in the production and transformation of light, for teaching in engineering, motivating students to learn. It enabled students to associate the different concepts in teaching the proposed theme with the functioning of technology. It also provided opportunities for articulation between research and teaching and university extension on the subject, with applications in photovoltaic production and sustainability in artificial lighting, involving students from the Civil and Environmental Sanitary Engineering course at the Universidade do Contestado (Reis, Reis Júnior, et al., 2020).

The use of photovoltaic technology in the teaching of Science and Mathematics in Engineering, as in previous research linked to the STEM movement (Dark, 2011; Kartal et al., 2015; Pecen & Nayir, 2010), can engage students to relate knowledge from classes to professional applications. The research demonstrated in arousing the interest of students in researching this application presented years later in Course Conclusion monographs, where often, projects involving photovoltaic technology (Biffi & Reis, 2020; Reis, Reis Júnior, et al., 2020; Schönell et al., 2020) or sustainability in artificial lighting (Both et al., 2021; Santos et al., 2019; Seffrin Júnior et al., 2021). Therefore, the study shows evidence of lasting learning and impact on sustainability promoted by teaching concepts in the photoelectric effect in engineering science classes using photovoltaic experiments. In an extension project, it was possible to take technology to Basic Education schools, explore with high school students, and motivate them to study engineering, as research shows the application of technology in other parts of the world (Dark, 2011; New York Academy of Sciences, 2017; Rose et al., 2010).

CONCLUSIONS

The use of photovoltaic cells as a context of application in the production and transformation of light into a photoelectric effect, from research linked to the STEM movement (Science, Technology, Engineering and Mathematics), was of singular importance for the teaching of the photoelectric effect theme in Physics in Engineering, all contexts considered, not only the learning of the concept itself.

The use of photovoltaic technology as an application context in the production and transformation of light in the teaching of Physical Sciences can motivate students to learn and help in the integration between academic knowledge and professional skills. The expansion of the diffusion of photovoltaic technology in education can, consequently, motivate society to use the Sun's energy in different technological applications in Engineering, as proposed by the STEM movement.

In addition, the system enabled the use of different artificial lighting technologies, contextualizing the students and allowing them to reflect on social changes resulting from scientific and technological evolution, as well as the social needs that this technological ascent provides. Furthermore, the inclusion of the experiment in photoelectric effect had repercussions on teaching, research, and extension, as an opportunity to engage academics of Civil Engineering and Environmental Sanitary Engineering at the Universidade do Contestado, where the research was carried out.

ACKNOWLEGMENTS

We thank the Universidade do Contestado for the financial support.

REFERENCES

Biffi, E., & Reis, M. A. F. (2020). RESUMO DE TCC: ESTUDO DE VIABILIDADE DE USINA SOLAR FOTOVOLTAICA EM POSTO DE COMBUSTÍVEL. *MIX Sustentável*, *7*(1), 171–172. https://doi.org/10.29183/2447-3073.MIX2020.v7.n1.171-172

Boitier, V., & Cressault, Y. (2011). Characterization of photovoltaic generators. *European Journal of Physics*, *32*(3), 657–674. https://doi.org/10.1088/0143-0807/32/3/003

Both, M., Reis Junior, P., Hentges, T. I., & Reis, M. A. F. (2021). Photoelectric effect on concrete artifacts produced with the addition of luminescent substances and polymer residues. *Journal of King Saud University - Engineering Sciences*. https://doi.org/10.1016/j.jksues.2021.08.003

Dark, M. L. (2011). A photovoltaics module for incoming science, technology, engineering and mathematics undergraduates. *Physics Education*, *46*(3), 303–308. https://doi.org/10.1088/0031-9120/46/3/008

Erickson, F. (1986). Qualitative methods in research on teaching. In *Handbook of Research on Teaching* (pp. 119–161).

Gfroerer, T. (2013). Circuits in the Sun: Solar Panel Physics. *The Physics Teacher*, *51*(7), 403–405. https://doi.org/10.1119/1.4820850

Jenkins, T. (2005). A brief history of . . . semiconductors. *Physics Education*, *40*(5), 430–439.

Kartal, O., Dunya, B. A., Diefes-Dux, H. A., & Zawojewski, J. S. (2015). The Relationship between Students' Performance on Conventional Standardized Mathematics Assessments and Complex Mathematical Modeling Problems. *International Journal of Research in Education and Science*, *2*(1), 239. https://doi.org/10.21890/ijres.07616

Klassen, S., Niaz, M., Metz, D., McMillan, B., & Dietrich, S. (2012). Portrayal of the History of the Photoelectric Effect in Laboratory Instructions. *Science & Education*, *21*(5), 729–743. https://doi.org/10.1007/s11191-011-9360-5

Kraftmakher, Y. (2008). Determination of the quantum efficiency of a light detector. *European Journal* *of Physics*, *29*(4), 681–687. https://doi.org/10.1088/0143-0807/29/4/003

Molki, A. (2010). Dust affects solar-cell efficiency. *Physics Education*, *45*(5), 456–458. https://doi.org/10.1088/0031-9120/45/5/F03

Morgan, M., Jakovidis, G., & McLeod, I. (1994). An experiment to measure the IV characteristics of a silicon solar cell. *Physics Education*, 252–254. https://doi.org/10.1088/0031-9120/29/4/014

New York Academy of Sciences. (2017). *Global STEM Alliance (GSA)*.

Pecen, R. (Reg), & Nayir, A. (2010). Promoting STEM to young students by renewable energy applications. *2010 Modern Electric Power Systems*, *13*(3), 1–8. https://doi.org/10.1108/14676371011077586

Reis, M. A. F. (2019). *Efeito fotoelétrico na produção e transformação da luz: investigação do uso de uma proposta didática para o ensino de física em cursos de Engenharia* [Universidade Luterana do Brasil]. http://www.ppgecim.ulbra.br/teses/index.php/ppgecim/article/view/336

Reis, M. A. F., Geller, M., & Serrano, A. (2021). Computer simulations for the teaching of photoelectric effect. *RENOTE*, *19*(1), 298–308. https://doi.org/10.22456/1679-1916.118488

Reis, M. A. F., Prochnow, T. R., & Serrano, A. (2020). Ciências e Matemática em Pesquisas Pertinentes às Células Fotovoltaicas de Silício na Engenharia. *Revista de Ensino de Engenharia*, *39*(1), 39–49. https://doi.org/10.37702/REE2236-0158.v39p39-49.2020

Reis, M. A. F., Reis Júnior, P., & Perin, D. L. (2020). Sustentabilidade energética em escola pública. *MIX Sustentável*, *6*(3), 37–44. https://doi.org/10.29183/2447-3073.MIX2020.v6.n3.37-44

Reis, M. A. F., & Serrano, A. (2017). Pesquisa bibliográfica em historicidade, conceitos e contextos na produção e transformação da luz com a teoria quântica. *Acta Scientiae*, *19*(3), 493–516. http://www.periodicos.ulbra.br/index.php/acta/article/view/3033/2419

Reis, M. A. F., & Serrano, A. (2019). *Guia para uso de tecnologia fotovoltaicas em laboratório real de Física*. Objetos Educacionais.

Richards, A. J., & Etkina, E. (2013). Kinaesthetic learning activities and learning about solar cells. *Physics Education*, *48*(5), 578–585. https://doi.org/10.1088/0031-9120/48/5/578

Rose, M. A., Ribblett, J. W., & Hershberger, H. (2010). Employing the Experimental Method to Inform Solar Cell Design. *Journal of STEM Education*, *11*(5), 55–63.

Santos, G. P. Dos, Reis Junior, P., & Reis, M. A. F. (2019). Uso do LED na eficiência energética e na sustentabilidade da produção de aves. *Saúde e Meio Ambiente: Revista Interdisciplinar*, *8*, 42–57. https://doi.org/10.24302/sma.v8i0.1900

Sark, W. G. J. H. M. van. (2007). Teaching the relation between solar cell efficiency and annual energy yield. In *European Journal of Physics* (Vol. 28, Issue 3, pp. 415–427). https://doi.org/10.1088/0143-0807/28/3/004

Schönell, R., Biffi, E., Rogovski, B., & Reis, M. A. F. (2020). ESTUDO COMPARATIVO ENTRE FOTOVOLTAICOS FLEXÍVEIS E TRADICIONAIS EM TOLDOS DA UNIVERSIDADE. *Revista Gestão & Sustentabilidade Ambiental*, *9*(2), 536. https://doi.org/10.19177/rgsa.v9e02020536-550

Seffrin Júnior, C., Pilonetto, E. L., & Reis, M. A. F. (2021). ESTUDO PÓS-RETROFIT NA SUBSTITUIÇÃO DA ILUMINAÇÃO PÚBLICA TRADICIONAL POR TECNOLOGIA LED NA CIDADE DE CONCÓRDIA. *15ª Jornada de Iniciação Científica (JINC)*, 22–23. http://www.cnpsa.embrapa.br/15jinc/index.php?pg=12

Tao, P.-K., & Gunstone, R. F. (1999). The process of conceptual change in force and motion during computer-supported physics instruction. *Journal of Research in Science Teaching*, *36*(7), 859–882. https://doi.org/10.1002/(SICI)1098-2736(199909)36:7<859::AID-TEA7>3.0.CO;2-J

ADDING FICTION INTO PHYSICS' LABS TO ENGAGE UNDERGRAD STUDENTS

Frédéric Bouquet[1], Julien Bobroff[1], Marine Moyon[2,3], Vincent Berry[4], Geneviève Allaire-Duquette[5]

[1]Université Paris-Saclay, CNRS, Laboratoire de Physique des Solides, 91405, Orsay, France.

[2]Institut Villebon Georges Charpak, 91400, Orsay, France.

[3]Université Paris Saclay, Research Action Chair on Educational Innovation, 91400 Orsay, France.

[4]EXPERICE, Labex ICCA, Université Sorbonne Paris Nord, France.

[5]Université de Sherbrooke, Sherbrooke, Canada.

Learning experimental physics is often perceived as being poorly engaging by students, especially at the university level. We wanted to test whether an immersive format could increase student engagement in experimental physics. Twenty-eight (M ± SD = 20.4 ± 1.0 year-old; 19 males) third year university science students were immersed into a fictional scenario. The learning goals were centered on experimental methodology and transverse skills, such as teamwork. They were all given a role in a story that unfold during the class (i.e. not unlike a live-action role play). All of them had to perform physical measurements, not because their teacher asked for it but because the scenario they were going through required it. We measured the impact of the fictional scenario on the students' behavioral, emotional and cognitive engagement by comparing with teaching as usual. The results show that students' emotional engagement was higher in the context of immersion ($p<0.001$). No behavioral or cognitive effects were found. Student transcripts confirm that students enjoyed the use of fiction, and that the learning goals were achieved. We were concerned that fictional scenarios could result in differentiated effects among gamers; we found no correlation between the students' game culture and any engagement scores. The use of fiction in teaching experimental physics therefore appears to be beneficial for the emotional engagement of students. It would be interesting to test the use of an immersive scenario in other contexts where engagement is known to be poor.

Keywords: Emotion, Physics, Context-based learning

INTRODUCTION

A central objective of physics education is to foster experimental abilities such as modeling, designing experiments, and analyzing data (Kozminski et al., 2014). However, students do not always appreciate physics' labs, particularly in the case of cookbook laboratories where students follow a precise protocol with no margin for autonomy. As physics teachers, we became interested in the question of student engagement, and how to adapt our practices to increase it. We wanted to test whether the use of an immersive approach had an impact on the engagement of our students. To do so we developed a new teaching in which all participants (students and teachers) play a role and must act accordingly. The students perform physics experiments in response to the story they are immerged in.

DESCRIPTION OF THE NEW TEACHING

The pedagogical objectives are to let students work on their experimental skills, in particular letting them build experimental devices that they design themselves. In addition, this teaching includes transversal objectives such as teamwork, resolution of open-ended problems, and finally pleasure of doing physics.

The principle of this new teaching is that students are immersed in a scenario that will encourage them to perform some physics experiments. As in a life-size role-play (LARP), all participants (students and teachers) play a role and must act accordingly. However, in contrast to LARP, students have no specific back story or different set of agendas. They behave as they would naturally and try to solve the different problems that arise. Their roles are generic and similar: they play the role of young scientists, (e.g., an engineering team), who provide technical support for people in difficulty (e.g., spies, astronauts, …). An unforeseen crisis forces them to quickly work on a series of experimental devices needed by non-player characters. The teachers are characters that have no particular physics knowledge but which are responsible for the organization (human relation managers for example): this allows them to keep the responsibility of the schedule while justifying their inability to help the students in the scientific tasks, giving students a large autonomy in their organization and production. Teachers can occasionally switch character if the scenario requires it. A typical example is when a scientific expert is needed: changing a nametag and a piece of clothing is enough to do so. For the immersion to work, teachers must play their roles seriously, as if it was real, but there is no need for good acting skills: they benefit from the students' willing suspension of disbelief (Muckler 2017). This concept, which describes the fact that one is willing to accept a story in order to enjoy it, allows, for example, to seriously consider the different ways to interact with extraterrestrials. Small details (e.g., nametags, graphical charter of all documents, …) help with this. Interactions with the non-player characters and progress in the scenario are conducted through webchats or mails, and also through audio and video messages that have been prepared in advance.

From a practical point of view, this teaching takes up two consecutive full days. It is intended for third-year university students (~30 students / year) in a math / physics curriculum with a very formal approach to physics, and is supervised by two teachers. Prior to these two days, the students are made aware of the objectives and principles of this teaching.

The fiction begins with a convocation letter that is sent to the students, with the date and location (not their usual classrooms, but one from another section of the university). At the beginning of these two days an icebreaking activity is organized, but the given reason for the convocation is an excuse: very rapidly after the icebreaker a crisis is triggered which requires the team to respond to an external demand for technical assistance (for example, a very secret space mission is about to land on an unknown planet and needs help). The story is organized around a series of scientific activities, each activity advancing the scenario, and leading to the next activity. We typically plan for four activities, of about half a day each. These activities are open problems that do not have unique solutions, but require students to build, test, and often document experimental devices. The physics involved is rarely complicated (mainly mechanics and small electronics), and the equipment available is not very advanced: for example, students must design a device to send a camera as far as possible without damaging it. The difficulties for the students are often to organize themselves, and to fully carry out the realization of the requested device, including testing and comparing their results. The scenario sometimes allows for some different outcomes depending on the quality of students' work, but generally the scenario is constructed to avoid complete failure in order to ensure a better experience for the students.

The fiction closes with an end credit, which allows everyone to get back their own identity. A collective debriefing is then organized in order to recontextualize the teaching, to listen to the students' feedback, and to give them feedback on their work.

CONCEPTUAL CONSIDERATIONS

Engagement is a multi-dimensional construct that can describe a student's actions and emotions (Fredericks et al., 2004). In this study, three dimensions were used: the behavioral engagement, which encompass student participation in class activities and outside activities; the emotional engagement which encompass emotions and feelings related to the educational environment; the cognitive engagement, which encompass the learning practices and strategies. It is worth noting that student engagement defined as such can evolve in time and differ between different topic.

MATERIAL AND METHODS

A new version of Parent's survey was used to capture student engagement, (Parent, 2017). Originally each dimension of engagement was measured by 10 questions; we kept 5 for behavioral engagement, 10 for emotional engagement, and 8 for cognitive engagement. To establish an engagement score we took the average of the responses, using the values 1 to 4 of the Likert scale, 4 being the maximum engagement.

Thirty-on students followed the immersive teaching. The same students followed a second teaching with very similar pedagogical objectives, also using active pedagogy but without any immersion. During two non-consecutive days, supervised by other teachers, students had to build up from scratch an experimental setup to study a physics phenomenon. The same engagement survey was given to the students after this class. In the rest of this article, "Immersion" will point to the first teaching, "teaching as usual" to the second. Both surveys also contained open questions at the end to collect students' verbatims and impressions. Of the 31 students, 28 students ($M \pm SD = 20.4 \pm 1.0$ year-old; 19 males) answered both surveys. The statistical analyzes were carried out by performing parametric tests after having verified that the normal distribution correctly describes the results.

We were concerned that, due to the game-like aspect of this teaching, their gaming habit could have an influence on their engagement, and we tested this parameter. To establish the game culture of the students, we adapted a survey made by Berry et al. (in press) used to measure the game culture of the French population. These answers were transformed into a 0-100 scale gaming score, 0 denoting a student that has never played any games, 100 a student who plays often many games. The value of this score has no absolute meaning but it allows to class students and look for correlation between gaming habits and engagement scores. In addition, we also specifically asked the students if they had ever participated in a LARP. The immersion teaching has many common features with LARP, and we tested if there were significant differences in the engagement between the students who had already participated in a LARP and those who didn't.

RESULTS

Cronbach's alpha test gives 0.81, 0.40, and 0.62 for the survey questions related to affective, behavioural, and cognitive engagement respectively. The engagement scores after both teachings are presented in Table 1. For each engagement type, a paired t-test was used to look for significant differences. No significant differences were observed for the behavioral and cognitive engagement scores, but the students were significantly more engaged during the immersion class than during the teaching as usual, see Figure 1 (β=0.36, $F(1,27)=15.81$, $p<.001$, PRE=.37, IC 95%[0.17,0.55]).

Table 1. Engagement scores for our 28-student population (mean ± standard deviation). Null engagement is 1, maximum is 4.

Teaching	Behavioral engagement	Emotional engagement	Cognitive engagement
Immersion	3.05 ± 0.33	3.41 ± 0.34	3.22 ± 0.39
As usual	3.02 ± 0.44	3.04 ± 0.49	3.10 ± 0.37

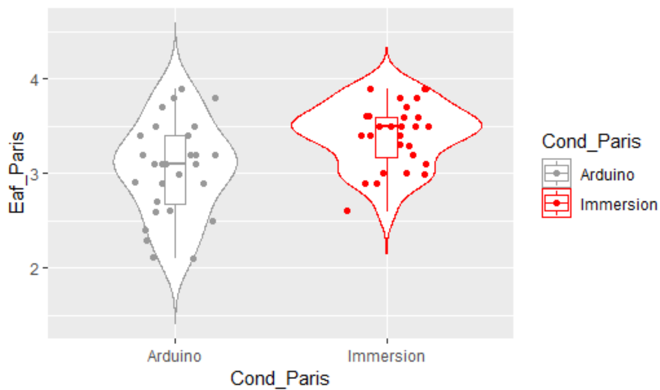


Figure 1. Students' emotional engagement during the immersion and the reference teaching, on a scale from 1 to 4, 4 being the most engaged.

The average gaming score for students is 41.1 ± 10.1, with 0 indicating a student who has never played any games, and 100 a student who plays various games a lot. The correlation coefficients between this gaming score and the engagement scores are not significant for behavioral, emotional, and cognitive engagement. Among the 28 students, 15 answered that they had already participated in a life-size role-play. However, we found no significant effect of this experience neither on emotional nor behavioral or cognitive engagement. There was no gender effect but the small sample size makes this result questionable.

The students' transcripts contain many answers where the fiction was mentioned in relation to their emotional engagement. The role of teamworking was also often mentioned (translated):

- *"[fiction] It motivated us more to do the different tasks";*

- *"I loved that the teachers were fully in their roles until the end, it pushed us to play the role, and it made the experience unique and very interesting, it's a great way to introduce people to science";*
- *"An amazing experience";*
- *"[fiction], it allowed us to get out of school and work in a good atmosphere. [I learned] Mainly to work in a group, to integrate myself, to impose my point of view while knowing how to listen to that of others, to make compromises ..."*

DISCUSSION

The Cronbach's alpha test performed on our survey shows that it correctly measures affective and cognitive engagement; the measurement of behavioral engagement is not as good (Nunnally, 1978). The original survey has been validated but the part measuring the behavioral dimension of the engagement is the part that we reduced the most (only five of the ten questions were kept), which could explain this difference.

The main result is that the students' emotional engagement was significantly higher during the immersive teaching than during the teaching as usual ($p <.001$), without the other forms of engagement being significantly modified in one way or another. Both teachings had the same duration, the same pedagogical objectives (experimental methodology in physics in the broad sense), both used an active pedagogy, with open problems of physics and with large student autonomy: the most likely cause for this increase of positive emotions in the students is the use of fiction during the immersion teaching. Another important result is that this increase did not happened at the expense of the other dimensions of engagement, cognitively or behaviorally. It is however impossible to refute the existence of other biases between the two teachings. We tried to minimize these biases as much as possible. The students' transcripts provide support for the idea that using fiction was a crucial point as it was often mentioned in a positive manner.

These results can be linked to reports that gamification in education generally increases engagement (Hamari et al., 2014). No correlation was observed between the engagement scores and the gaming scores of our students, nor with whether they had already participated to a LARP or not. The use of fiction did not create a noticeable bias between our students. The fact that the game culture does not correlate with the engagement score is surprising. However, our population (young science students) possesses a higher game culture than the rest of the general population (Berry et al., in press) and is likely to be homogeneous with regard to gaming habits.

CONCLUSION

The use of fiction in our teaching increased the emotional engagement of students. This occurred independently of our students' game culture, measured in two different ways. In addition, the transcripts show that our educational objectives were achieved according to the students. However, the statistical power could be increased with larger-population studies. The principle of using a scenario is not restricted a priori to experimental physics and could be applied to other teachings. Proposing different and original teaching formats seems an effective way to break the monotony of yearlong training and to offer students a teaching experience that affects them emotionally; this is undoubtedly all the more important this year when many teachings are done remotely with very little direct human contact.

ACKNOWLEGMENTS

We thank Ulysse Delabre and Philippe Barberet for participating to the creation of this new kind of teaching, and Martin Riopel and Diane Leduc for discussions and inspiration. This work has been partially supported by the Chair "Physics Reimagined" led by Paris-Saclay University and sponsored by AIR LIQUIDE, and is part of the Research Action Chair on Educational Innovation from Paris-Saclay, held by Martin Riopel and financed by the École Universitaire de premier cycle de l'université Paris Saclay. This chair exists thanks to Jeanne Parmentier, Isabelle Demachy, and Martin Riopel, and benefits from the monitoring and methodological support of Patrice Potvin, Christian Bégin, Diane Leduc, and André-Sébastien Aubin.

REFERENCES

Berry, V., Coavoux, S., & Minassian, H. T., *Les Français et les jeux*, [in press], INED.

Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School engagement: Potential of the concept, state of the evidence. *Review of educational research, 74(1),* 59-109.

Kozminski J., Beverly N., & Lewandowski H. (2014), *American Association of Physics Teachers Recommendations for the Undergraduate Physics Laboratory Curriculum*. American Association of Physics Teachers (AAPT). https://www.aapt.org/Resources/upload/LabGuidlinesDocument_EBendorsed_nov10.

Hamari, J., Koivisto, J., & Sarsa, H. (2014, January). *Does gamification work? – a literature review of empirical studies on gamification*. In 47th Hawaii international conference on system sciences (pp. 3025-3034).

Muckler, V. C. (2017). Exploring suspension of disbelief during simulation-based learning. *Clinical Simulation in Nursing*, *13*(1), 3-9.

Parent, S. (2017). *L'engagement d'enseignants, la variation de l'engagement d'étudiants sur une base trimestrielle et la présence de conditions d'innovation en situation d'enseigner et d'apprendre avec le numérique au collégial / Teacher Engagement, Variability of Student Engagement on a Trimestrial Basis and Presence of Innovation Conditions for Teaching and Learning With Digital Tools and Resources at the College Level*. Doctoral dissertation, Laval University.

Nunnally, J. C. (1978). *Psychometric theory*. New York: McGraw-Hill.

RELATING TEACHING ASSISTANTS' BELIEFS ABOUT TEACHING AND LEARNING TO THEIR INSTRUCTIONAL PRACTICES IN AN INTRODUCTORY PHYSICS TUTORIAL

May Lee

University of Groningen, Groningen, The Netherlands

Teaching assistants (TAs) influence the quality of undergraduate education, but little research has been published about their instructional practices. In this study, I investigated three TAs' enacted instructional practices during tutorials for an introductory physics course at a Dutch university and related those enactments to their expressed beliefs about teaching and learning. Video-recordings of the TA's tutorials and transcripts of their interviews were analyzed using two previously developed protocols. The TAs enacted some of the same instructional practices (e.g., asking students if they had questions about the previous tutorial), but expressed different beliefs for enacting those practices (i.e., help students understand concepts, ensure students enjoy being in the tutorial, help students solve assigned exercises). These findings suggest that TAs' beliefs about teaching and learning should be an important consideration when addressing possible change(s) to their instructional practices during tutorials (e.g., weekly TA meeting, TA professional development).

Keywords: higher education, teaching beliefs and practices, introductory physics tutorials

INTRODUCTION

Undergraduate students primarily cite poor teaching in their courses as one of the main reasons for switching out of science fields (Seymour & Hunter, 2019). Because these students often spend more individualized time with their teaching assistants (TAs) during tutorials than with their course instructors during lectures (Blatchford et al., 2012), improving our understanding of TAs's enacted instructional practices can help inform our structuring of tutorials that encourage and support students' learning of science and persistence in science fields. One theoretical framework that can be used to explain relations between the TAs, students, science content, and tutorial learning environment is Schwab's (1983) four commonplaces (teacher, student, curriculum, milieu). This framework indicates that the enactment of instructional practices that support students' learning of content requires coordinating the commonplaces.

Beliefs about teaching and learning greatly influence the instructional practices that are enacted during class. For instance, Wallace and Kang (2004) found that science instructors who associated successful science learning with deep conceptual understanding primarily used verification labs to illustrate those concepts. They also found that science instructors who associated successful learning with enculturation into science practices used inquiry-based labs to provide opportunities for students to engage with scientific practices. Their finding illustrate how beliefs about teaching and learning may influence the enacted instructional practices.

In contrast to Wallace and Kang (2004), others researchers found similarly enacted instructional practices were associated with varied beliefs about teaching and learning (Goertzen et al., 2010; Speer, 2008). In Speer's (2008) study, the TAs indicated the importance of asking students questions (instructional practice). However, one TA asked questions in order to diagnose the strength of students' conceptual understanding and help them overcome any difficulties in doing so; the other TA asked questions to model behaviors that he wanted students to emulate when problem-solving and to monitor their learning so that students would complete the same problems in a timely manner. Similarly in Goertzen et al.'s (2010) study, each TA checked for students' understanding of target ideas (instructional practice); however, the TAs' beliefs for enacting that practice varied, especially with respect to their self-perceived roles (e.g., help students grapple with traditional problems, ensure students have the right answer, get students going in the right direction).

These findings suggest further investigation is needed about the relationships between TAs' enacted instructional practices and beliefs about teaching and learning, which I address in this study. My research questions were: *What instructional practices did TAs enact during their tutorials? What beliefs about teaching and learning did TAs express about their instructional practices? How did the TAs' enacted practices compare to their expressed beliefs?*

METHODS

To conduct an in-depth investigation of multiple participants' perspectives of an activity situated within a natural context, I used a multiple case study (Yin, 2008); this design helps identify and analyze similarities and differences between individual cases. The two-hour tutorials, which met at the same times twice per week and at possibly different locations, were part of a 20-week introductory physics course at a large university in The Netherlands; student attendance during tutorials was recommended but not mandatory. Of the nine TAs who support this course, three consented to participating in this study—one male undergraduate student ("Coen") and two male master's students ("Daan" and "Lars"). Each TA had prior experiences with this course, in addition to being a TA for other courses.

Data Collection

Data sources included field notes or video-recordings of each TA's tutorials and an audio-recorded interview with each TA. Figure 1 shows the data colletion sources and schedule.

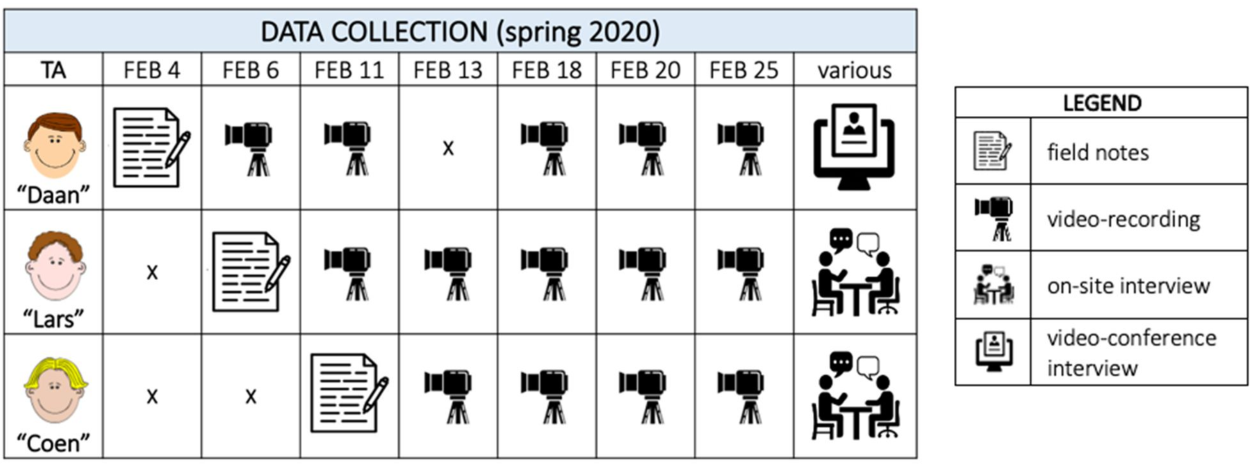


Figure 1. Data collection schedule.

The field notes were organized by addressing Schwab's (1983) four commonplaces of teaching and focused on (a) descriptions of TAs' activities (e.g., solving exercises on chalkboard, talking with students), (b) descriptions of students' activities (e.g., working with friends), (c) concepts that were addressed during the lectures (e.g., divergence, electrostatics), (d) questions about aspects of the tutorials from student's perspectives (e.g., attending tutorials scheduled over lunch, online vs. onsite tutorials), and (e) questions about aspects of the tutorials from the TA's perspective (e.g., using two different rooms each week).

For the video-recordings, the cameras were set-up in each room by a graduate student and myself. We set-up the video-cameras at the back of the room and aimed them towards the the front of the room, which was where the TA was often located and to avoid recording students' faces. Once the video-cameras started the recording, the graduate student (or I) left the room to minimize outside intrusion; we returned at the end of tutorial to stop the recordings and collect the cameras. These video-recordings continued until the tutorial after the first exam (third week of course). Afterwards, they were content-logged (same format as field notes, with time stamps) and partly transcribed for analysis.

The semi-structured interviews were conducted towards the end of the course. Informed by the field notes and content logs of the video-recordings, I designed interview prompts to address four constructs: (a) beliefs about teaching (e.g., "What is your role as a TA?"), (b) beliefs about learning (e.g., "How do you think students learn electricity/magnetism?"), (c) descriptions of tutorial activities (e.g., "What do you do on a typical day?"), and (d) considerations of alternate curricula (e.g., "What are your thoughts about this [proposed] tutorial activity?"). Some of the interview prompts could address multiple constructs. The audio-recorded interviews for Coen and Lars were conducted in person; Daan's interview was audio-recorded through a video-conference due to COVID-19 constraints. The audio-recordings of the interviews ranged between 1.5 to 2.5 hours and were fully transcribed.

Data Analysis

My analysis involved comparing the TAs' enacted instructional practices across tutorials, characterizing the interview responses with respect to their beliefs about teaching and learning, and identifying (any) relations between the instructional practices and beliefs. I selected two instruments to help me achieve these goals.

- *Real-time Instructor Observing Tool* (RIOT; Paul & West, 2018). This can be used to qualitatively describe the TAs' activities (from field notes and video-recordings) with respect to their interactions with students (i.e., talking at them, dialoguing with them, observing them, not interacting with them). I used the RIOT to code video-recording excerpts of the TAs' instructional activities.
- *Teacher Beliefs Interview* (TBI; Luft & Roehrig, 2007). This can be used to locate the TAs' beliefs about teaching and learning on a teacher- to student-centered continuum: traditional (most teacher-centered), instructive, transitional, responsive, and reform-based (most student-centered). I used the TBI to code interview excerpts of the TAs' responses with respect to their self-described instructional practices during tutorials, perceived affordances/constraints with the physical/social environments, and perspectives on aspects of other instructional strategies (e.g., group work).

Beliefs about teaching and learning are tacit and must be inferred from congruences between instructors' descriptions of/intentions towards/enactments of teaching (Lombaerts et al., 2009).

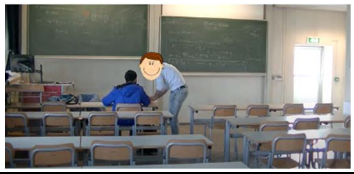
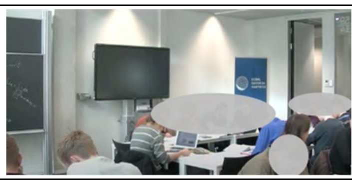
I used grounded theory (Corbin & Strauss, 2007) to develop in-vivo codes describing the TAs' enacted instructional practices and responses to interview questions. This process occurred iteratively and in parallel with both data sources. A researcher external to the project checked a subset of the codes for credibility, neutrality, and consistency. After both data sources were coded, I used thematic analysis (Braun & Clarke, 2006) to identify patterns in the data based on the theoretical concepts addressed in the RIOT and TBI. Video excerpts and interview quotes that did not require extensive references to other parts of the videos/interviews were selected to illustrate examples of each TA's instructional practices and beliefs about teaching and learning.

FINDINGS

Enacted Instructional Practices (video-recordings)

For each TA, snapshots from the beginning, middle, and end of the video-recorded tutorial on February 18 are shown in Table 1. This tutorial was chosen because students had already been attending tutorials for two weeks (enough time for TAs and students to develop a routine) and the exam was scheduled for the following week. For Coen and Daan, the desks in their room were placed in rows, facing the chalkboard at the front of the room; for Lars, the room was arranged such that there was one group of ten desks organized as a big circle and smaller pairings of two or three desks (arranged by the previous class). Although the room arrangement and organization of activities differed for each tutorial, the TAs enacted some of the same instructional practices.

Table 1. Snapshots from beginning, middle, and end of the tutorial on Feb 18 for each TA.

	beginning	middle	end
Coen			
Daan			
Lars			

Coen started tutorial by writing the assigned exercises on the chalkboard and then asking students about the lecture. He then reminded them about the upcoming exam and shared some test-taking strategies. Coen spent the majority of his time sitting at the front of the room. When a student (infrequently) raised his/her hand, Coen walked over to explain the answer(s); afterwards, Coen would glance around the room before returning to his seat. This tutorial ended about ten minutes early, when the last students left the room.

Lars said he typically starts tutorial with a greeting, sometimes asking students about the previous lecture, before writing the assigned exercises on the board. In this tutorial, Lars spent the majority of his time walking around the room to see how the students were progressing on the exercises. Lars rarely stayed in any part of the room for an extended period of time and his interactions with students were usually one-on-one; he rarely addressed the whole group. Lars also rarely went to the chalkboard to write explanations. At the scheduled end of this tutorial, Lars was helping two students; a few students were working independently.

Daan started tutorial by apologizing for his previous absence and then telling students he would present a few exercises that previous students found difficult. After writing the givens for an exercise on the chalkboard, Daan asked students how they would proceed for each step of the solution and gave feedback with respect to its correctness. During the second half of the tutorial, he walked around the room to address individual questions, occasionally addressing the whole tutorial if the same question was raised by multiple students. At the scheduled end of this tutorial, Daan was still helping one student; the rest of students had already left.

Using the RIOT, the enacted instructional practices can be described as primarily observing students for Coen; observing and dialoguing with students for Lars; and talking at, observing, and dialoguing with students for Daan.

Beliefs about Teaching and Learning (interviews)

The TAs expressed different beliefs about teaching and learning, which was reflected in the responses about their self-perceived roles (Table 2) and descriptions of activities during a typical day in their tutorials (Table 3).

With respect to their roles, the TAs responses indicated that they prioritized helping students: solve the assigned textbook exercises (Coen), have fun and make progress on the book exercises (Lars), and understand concepts and learn problem-solving tools (Daan).

Table 2. TAs' descriptions of their self-perceived roles.

	Responses to: "How would you describe your role as a TA for this course?"
Coen	"Well I think that really differs per person, everyone does it in their own way. Um, but my, my goal was kind of to try and help them solve the assignments, not to completely show them, like a mini lecture on how to do it. Uhh, I prefer them to work on it themselves. But I wanted to give them the time as well. So, it's kind of why I usually I ask if there's any questions about the assignments from previous tutorial and then I will do those on the board. Also, I would ask because doing them all is way too much."
Lars	"I see myself as a guide to make sure that people have fun and progress during the making of the [book] exercises. That is my main goal. And of course, that means that sometimes you have to do a bit more than just give answers or give hints towards answers. So, you should-I don't know-tell something about some physical intuition you can have for certain situations or some context-'when is something used.' To be very fair, I'm not very good at context. That's something I think other TAs are really good-and a bit better-at. A bit better, I think, in building physical intuition for things. And then joking around that makes people come to the tutorial even when they don't necessarily feel like it would be the best use of their time- because in the end, I think tutorials are a best use of their time."
Daan	"So, I think as a TA it's, um, your goal or your aim should be to, in the first place, I think clarify stuff that was not really completely clear from the lecture. So, that's what I, what I always start with. And secondly, well basically just help them to kind of get a right set of tools with which they can actually solve the problem. So, it's not really doing all the, all the problems completely on the, on the Blackboard. Well more guiding, I, I think guiding them and providing them with a, with a

	set of tools to um, just solve, solve the problems that they are given. I think that's, that's the role overall. Yeah. And also, maybe to get feedback about, uh, the lectures about whether it was doable or not and then transfer that back or feedback back to the lecture. I think those are, for me, those are, I think the main, summarizing points for what I do as a TA…"

The TAs' descriptions of the activities during a typical tutorial session also differed. Coen indicated his instructional practices were to complement lectures and address lingering questions from previous tutorials. For Lars, his responses highlighted his social interactions with the students. Daan's brief response addressed helping students understand the book exercises, which was described more fully in his responses to other prompts (e.g., response to self-perceived role as TA in Table 2).

Table 3. TAs' descriptions of a typical day in their tutorials.

	Responses to: "How would you describe a typical day in your tutorial?"
Coen	"…I usually start by saying 'Ok, we have these questions', uh, the past few weeks I've also been asking on updates how the lectures are going, because I heard that the lectures are slightly behind. … So, I improvise the lectures kind of during the tutorials. …if the lectures are behind, um, then I would, uh, well actually first I would do the, I would ask if there's any questions about the previous tutorials or I would ask if they finished everything."
Lars	"I walk in, I say 'good afternoon, good morning,' whatever. Good morning, because it's always in the morning. And sometimes I ask 'How was the lecture?' and I write down the tutorial questions that they need to do – from memory, on the board, because that's an inside joke I have with them. I remember the problems that we need to do by heart. And then people start working – usually in the beginning, it's quite, quite quiet – yeah – because everybody's reading the question, trying to solve it for themselves at first. … Yeah, then during the tutorials, more and more conversations start to form and I, I get more busy – yeah – running around. Usually the last hour or hour and a half, I'm usually answering questions. … usually what you see is that if people, if they're done with a question and there is only 5 to 10 minutes left, they leave. And yeah, I think I think that's fair enough. I don't want to force people to stay. But sometimes people are still working on something when it's 49 minutes – usually we end at 45 minutes. Sometimes I've got something else to do directly after the tutorial. … There's not really a designated end. I don't end things centrally, generally speaking."
Daan	"…they [students] just do the exercises [on typical tutoral day]. Uh, and I try to help them or I do stuff on the blackboard…"

Using the TBI, the TAs' beliefs about teaching and learning was characterized as instructive for Coen, transitional for Lars, and a combination of instructive and transitional for Daan.

DISCUSSION

The description of each TA's tutorial classroom, enacted instructional practices (and associated RIOT categories), and expressed beliefs about teaching and learning (and associated TBI categories) are shared below in Table 4.

Table 4. Summary of TAs' beliefs (interviews) and enacted instructional practices (video-recordings).

	Coen	**Lars**	**Daan**
Classroom	▪ 16 students ▪ chairs/tables in rows	▪ 22 students ▪ chairs/tables in rows and circles	▪ 32 students ▪ chairs/tables in rows

Enacted instructional practices	▪ wrote assigned exercises on board ▪ asked about previous exercises ▪ waited at the front of the room for students to ask questions	▪ wrote assigned exercises on board ▪ asked about previous exercises occasionally ▪ walked around and talked with one or few students on previous exercises and/or social well-being	▪ wrote assigned exercises on board ▪ asked about previous exercises ▪ guided students through select exercises and addressed individual questions
RIOT	*observing students*	*observing students, dialoguing with students*	*talking at students, observing students, dialoguing with students*
Beliefs about teaching and learning	▪ *role*: **helps students understand concepts** – expresses desire to have conceptual physics discussions with students ▪ *gauge progress*: difficult to do without students asking questions ▪ *success*: students need to ask questions	▪ *role*: **guides students in having fun** while sharing insights that help develop intuition for exercises ▪ *gauge progress*: looks at facial expressions or at written work on students' papers ▪ *success*: addresses success in course (study previous exams) vs. physics (develop intuition)	▪ *role*: **provide tools** that help students learn concepts; **communicate difficulties to instructor** ▪ *gauge progress*: looks at body language ▪ *success*: students need to be consistent with their notation and develop good study habits (hard work is its own reward); indicates physical intuition develops with repeated practice
TBI	*instructive*	*transitional*	*instructive and transitional*

Each TA enacted a few of the same instructional strategies, but expressed different beliefs about teaching and learning with respect to their self-perceived roles and definitions of student success. Using the RIOT (Paul & West, 2018) to analyze the video-recordings, an enacted instructional practice common across the TAs was *observing students*. Using the TBI (Luft & Roehrig, 2007) to analyze the interview transcripts, the TAs' beliefs about teaching and learning corresponded to different locations on the teacher- to student-centered continuum. These findings are consistent with the findings from Goertzen et al. (2010) and Speer (2008) – that the same enacted instructional practice may be motivated by different beliefs about teaching and learning. However, the characterizations reflect a partial snapshot of the TAs' enacted practices and expressed beliefs for a given context. One limitation is that the video-recordings captured only the first few weeks of tutorials; for instance, Coen said he used different instructional practices at the end of the course, partly because the topic had changed. This study also did not address the nature of the TAs' prior teaching experiences or the undergraduate students' interactions with their peers during tutorials, factors which can influence/contribute to their enacted instructional practices and/or beliefs about teaching and learning. Despite these limitations, these findings highlight key similarities/differences between the TAs' enacted instructional practices and beliefs about teaching and learning that can inform TA professional development designed to encourage and support students' learning of science and persistence in science fields.

ACKNOWLEGMENTS

I would like to thank Coen, Daan, and Lars for participating in this study, and the course instructors who welcomed my study into their course. I would also like to extend my thanks to Eirini Drymiotou for her assistance with the video-recording and the ISEC research group for their constructive feedback on my preliminary findings.

REFERENCES

Blatchford, P., Russell, A., & Webster, R. (2012). *Reassessing the impact of teaching assistants: How research challenges practice and policy*. Routledge.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Corbin, J., & Strauss, A. (2007). *Basics of qualitative research: Techniques and procedures for developing grounded theory* (3rd ed.). SAGE Publications, Inc.

Goertzen, R. M., Scherr, R. E., & Elby, A. (2010). Tutorial teaching assistants in the classroom: Similar teaching behaviors are supported by varied beliefs about teaching and learning. *Physical Review Special Topics - Physics Education Research*, *6*(1), 010105. https://doi.org/10.1103/PhysRevSTPER.6.010105

Lombaerts, K., De Backer, F., Engels, N., van Braak, J., & Athanasou, J. (2009). Development of the self-regulated learning teacher belief scale. *European Journal of Psychology of Education*, *24*(1), 79–96. https://doi.org/10.1007/BF03173476

Luft, J. A., & Roehrig, G. H. (2007). Capturing science teachers' epistemological beliefs: The development of the Teacher Beliefs Interview. *The Electronic Journal for Research in Science & Mathematics Education*. https://ejrsme.icrsme.com/article/view/7794

Paul, C., & West, E. (2018). Using the Real-time Instructor Observing Tool (RIOT) for reflection on teaching practice. *The Physics Teacher*, *56*(3), 139–143. https://doi.org/10.1119/1.5025286

Schwab, J. J. (1983). The practical 4: Something for curriculum professors to do. *Curriculum Inquiry*, *13*(3), 239–265. https://doi.org/10.2307/1179606

Seymour, E., & Hunter, A.-B. (Eds.). (2019). *Talking about leaving revisited: Persistence, relocation, and loss in undergraduate STEM education*. Springer. https://doi.org/10.1007/978-3-030-25304-2

Speer, N. M. (2008). Connecting beliefs and practices: A fine-grained analysis of a college mathematics teacher's collections of beliefs and their relationship to his instructional practices. *Cognition and Instruction*, *26*(2), 218–267. https://doi.org/10.1080/07370000801980944

Wallace, C. S., & Kang, N.-H. (2004). An investigation of experienced secondary science teachers' beliefs about inquiry: An examination of competing belief sets. *Journal of Research in Science Teaching*, *41*(9), 936–960. https://doi.org/10.1002/tea.20032

Yin, R. K. (2008). *Case study research: Design and methods* (4th ed.). Sage Publications, Inc.

EXPLORING BIOLOGY INSTRUCTORS' AND STUDENTS' CONCEPTIONS AND APPLICATIONS OF SCIENTIFIC HYPOTHESES AND PREDICTIONS

Anupriya Karippadath[1], Stephanie M. Gardner[1]

[1]Purdue University, West Lafayette, United States of America

Guidelines for undergraduate biology education identify evaluation and application of scientific hypotheses as an essential area of competency for biology majors. There is, however, clear evidence that undergraduate students need more support to fully grasp the concept and application of scientific hypotheses. Additionally, while established perspectives regarding the nature of scientific inquiry and experimentation emphasize hypotheses alongside the associated concept of "predictions", guidelines and resources for biology teaching rarely mention predictions. Furthermore, we see a lack of explicit definitions of these fundamental concepts in teaching resources. There is, hence, a clear indication of an implicit assumption of common understanding regarding the concepts, role, and application of hypothesis and prediction in the context of scientific inquiry. We explored this assumption via characterization of the variation in conceptions of hypotheses and predictions among biology faculty, graduate students, and students. We interviewed Biology faculty, graduate teaching assistants (TAs), and undergraduate students at a large, Midwestern, public University with very high research activity in the United States (US). Thematic coding of interviews used deductive codes derived from Karl Popper's 'The Logic of Scientific Discovery' and inductive codes derived from the data. We find that faculty members' conceptions of hypotheses and predictions – regarding concept, application, and role – align closely with Popper's perspective, while graduate TAs and undergraduate students' ideas are more varied. Undergraduate students' definitions suggest that they conflate the two concepts and both graduate TAs and undergraduates are less familiar with the definitions and use of predictions than hypotheses. Undergraduate students are less able to explain the role of hypotheses and predictions as compared to faculty and graduate students. Lastly, we discuss challenges and opportunities in student learning of these concepts identified by our different participant groups.

Keywords: Undergraduate, hypothesis, prediction, scientific inquiry

INTRODUCTION

The process of scientific inquiry is closely linked to the nature of science and is fundamental to our understanding of how scientific knowledge is developed (Lederman, 2006; Popper, 1959). Our explanation of the process of scientific inquiry has undergone some revision over time, especially in the context of teaching – from a linear "scientific method" that was popular in science textbooks for decades to the current description of a more complex process with interlinks between observation, theory, and experimentation (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Lederman, 2006; Mccomas, Clough, & Almazroa, 2005; Windschitl, Thompson, & Braaten, 2008). An idea that has persisted through the changes in established narrative about the process of and teaching practices regarding scientific inquiry is that of scientific hypotheses and predictions being critical to many types of scientific research.

In the context of experimentation, hypotheses can be generated from prior inquiry as well as serve to formally frame new investigations (Kell & Oliver, 2004). Scientific hypotheses (in contrast to statistical hypotheses) frame a novel claim within the established scientific framework and scientific predictions outline multiple lines of evidence necessary for supporting that claim. Karl Popper's seminal work 'The Logic of Scientific Discovery' (Popper, 1959) elucidated this concept and role of hypotheses and predictions in the context of scientific inquiry. Popper's perspective may be summarized as deductive falsificationist – a perspective still used to illustrate the "scientific method" in classrooms (Ruxton & Colegrave, 2011). Popper theorized that a hypothesis and a prediction are two components of a causal explanation for a phenomenon. Based on Popper's characterization, hypotheses and predictions should function to guide data collection and analysis in the process of scientific inquiry (Popper, 1959; Wilson & Rigakos, 2016). In this role, hypotheses and predictions are of particular importance in shaping experimental design, which is an essential part in the work of science researchers and in science education (Vision and Change; AAAS, 2011)

Current recommendations for undergraduate biology education explicitly state that evaluation of scientific hypotheses is an essential competency for biology majors and calling specifically for inquiry-based teaching and hypothesis testing to be included in undergraduate programs (AAAS, 2011). Assessment tools for biology education, a yardstick for teaching and learning expectations, include hypothesis recognition and evaluation as skills integral to scientific inquiry (Khodor, Halme, & Walker, 2004; Sirum & Humburg, 2011; Dasgupta, Anderson, & Pelaez, 2014; Deane, Nomme, Jeffery, Pollock, & Birol, 2014; Pelaez et al., 2017). However, these many guidelines fail to explicitly define what hypotheses, or predictions, are, how they are related to each other, and why they are important. Further, Dasgupta et al. (2014) documented evidence of challenges encountered by undergraduate biology students in grasping the concept and application of a hypothesis. They also found evidence that students may need additional guidance in other key aspects of experimental design and scientific claim validation such as determining the experimental variables, measuring the right relationship to validate a proposed explanation, and overall alignment of the experiment with the claim to be tested - all of which are aspects of experimental design that tie into the function of hypotheses and predictions as described by Karl Popper. The literature, thus, indicates that 1) there is an unverified assumption of common understanding of the concepts of hypotheses and predictions and their role in inquiry among scientists and educators, and 2) students face challenges in grasping these concepts. While it is likely that many of Popper's ideas endure, it is important for biology teaching to keep up with current scientific ideas and practices in scientific inquiry (AAAS, 2011). To ensure this, it is necessary to first evaluate current practices of biology researchers as well as the representation of these practices being conveyed to students. Accordingly, our exploratory study aimed to –

1) Compare faculty members', graduate students', and undergraduate students' conceptions of scientific hypotheses and predictions and their role in inquiry.

2) Reveal perspectives on challenges and opportunities in student learning of these same concepts identified by faculty members, graduate students, and undergraduate students.

DATA COLLECTION AND ANALYSIS

This study was conducted at a large Midwestern public doctoral University with very high research activity (IRB#1907022442). We recruited Biology faculty members (n=3), graduate teaching assistants (TAs) (n=7), and undergraduate students (n=7). The criteria for participation were a) for faculty – at least a 25% appointment within the Department of Biological Sciences b) for graduate TAs – must have been a teaching assistant for a minimum of one semester and c) for undergraduate students – must be majoring in biological sciences. We conducted semi-structured interviews with all participants. These interviews were designed to obtain detailed information about our research participants' conceptions of scientific hypotheses and predictions as standalone concepts as well as within the larger context of scientific inquiry. Interviews also included questions about challenges undergraduate students may face while learning the concepts of hypothesis and predictions (for undergraduate student participants these were self-reflection questions). Interviews were audio-recorded and transcribed, and transcripts were analyzed using thematic coding (Saldaña, 2013). Deductive codes were derived from the widely accepted perspective of Karl Popper (1959). Box 1 describes Popper's ideas of scientific hypotheses and predictions, and the deductive codes derived from them. Additional inductive codes were derived from the data. The complete dataset was coded by one researcher and a subset (20%) was independently coded by another researcher. Coding results were discussed to consensus.

Box 1: Deductive codes derived from Popper, 1959 (code terms are underlined).

HYPOTHESIS is a broad statement that provides a conceptual explanation for an observed phenomenon. Such an explanation must be deduced from prior knowledge, exclude alternative explanations (exclusive) and must be falsifiable.

PREDICTION is a specific statement that follows logically from the hypothesis and describes an effect (expectation) of the causal explanation. A prediction must be exclusive to one hypothesis and testable.

RELATIONSHIP BETWEEN HYPOTHESES AND PREDICTIONS:

Hypothesis is a broad statement, while prediction is specific (specificity). Prediction is derived logically from the hypothesis (order). Hypothesis and prediction have different roles in inquiry.

FINDINGS AND IMPLICATIONS

Analysis shows that faculty definitions of hypotheses (Fig. 1) and predictions (Fig. 2) are largely aligned with the Popperian perspective. Faculty members' conceptions of predictions are more consistent across participants and show more alignment with deductive codes as compared to conceptions of hypotheses. In contrast, responses from both TAs and undergraduate students were more variable and different from the faculty as well as more divergent from Popper's ideas (more inductive codes). Both these participant groups expressed fewer descriptive features while describing predictions, as compared to hypotheses – a trend not seen in faculty members. Undergraduate students' definitions suggest that they conflate the two concepts, with several descriptive features overlapping between the two.

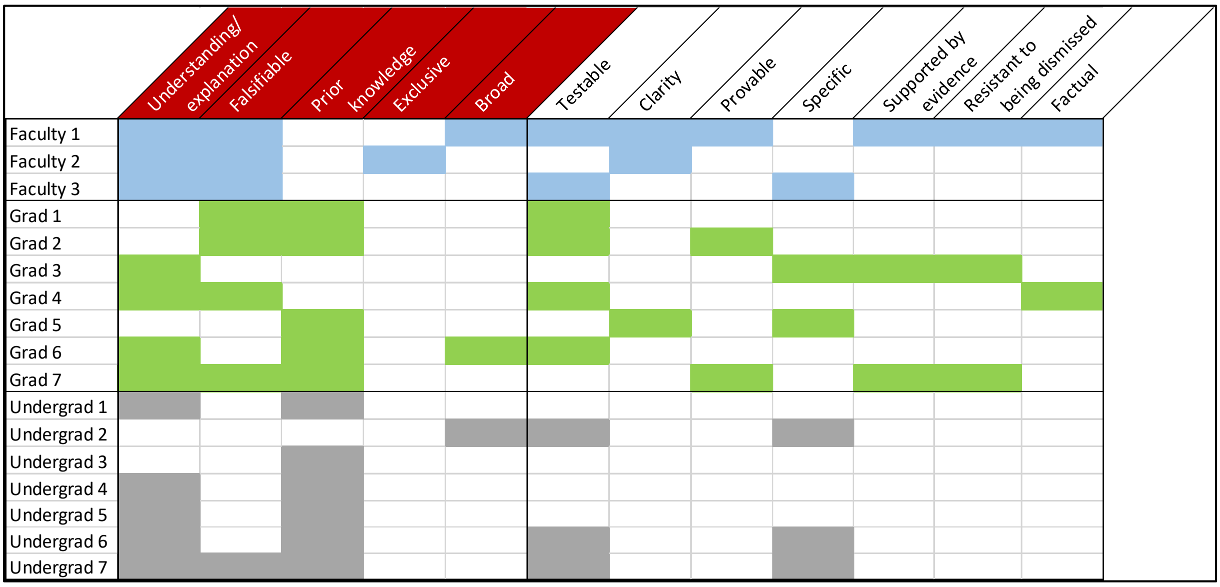


Figure 1. Participants' conceptions of scientific hypotheses. Red column headers indicate deductive codes. Highlighted cells indicate occurrence of a code in participant response.

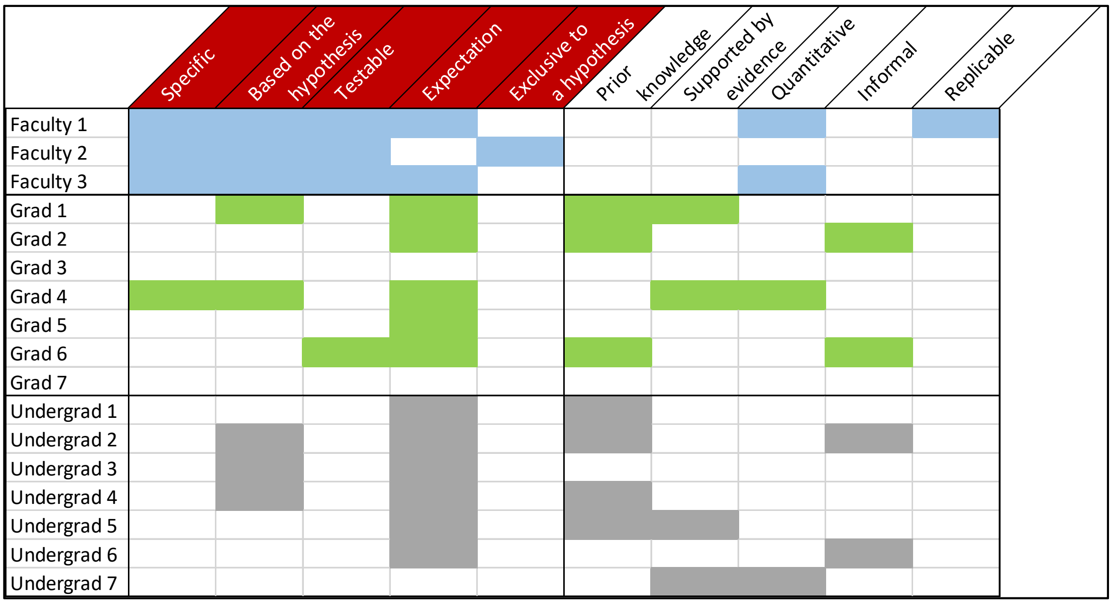


Figure 2. Participants' conceptions of scientific hypotheses. Red column headers indicate deductive codes. Highlighted cells indicate occurrence of a code in participant response.

Both faculty members and graduate students' conceptions regarding the role and importance of hypotheses and predictions in science align largely with Popper's perspective, though the data also revealed several inductive codes (Fig. 3). Undergraduate students had very few descriptive features for importance and role of these concepts, as compared to other participant groups. These findings suggest that both graduate TAs and undergraduate students may be relatively unfamiliar with the concept of a prediction, as compared to a hypothesis. Faculty, on the other hand, seem to have narrowly defined conceptions of the concept and application of predictions which align with the Popperian perspective. Both faculty and graduate students shared detailed and varied perspectives on the role of hypotheses and predictions in scientific inquiry, but undergraduates did not show much knowledge about application and importance of these concepts.

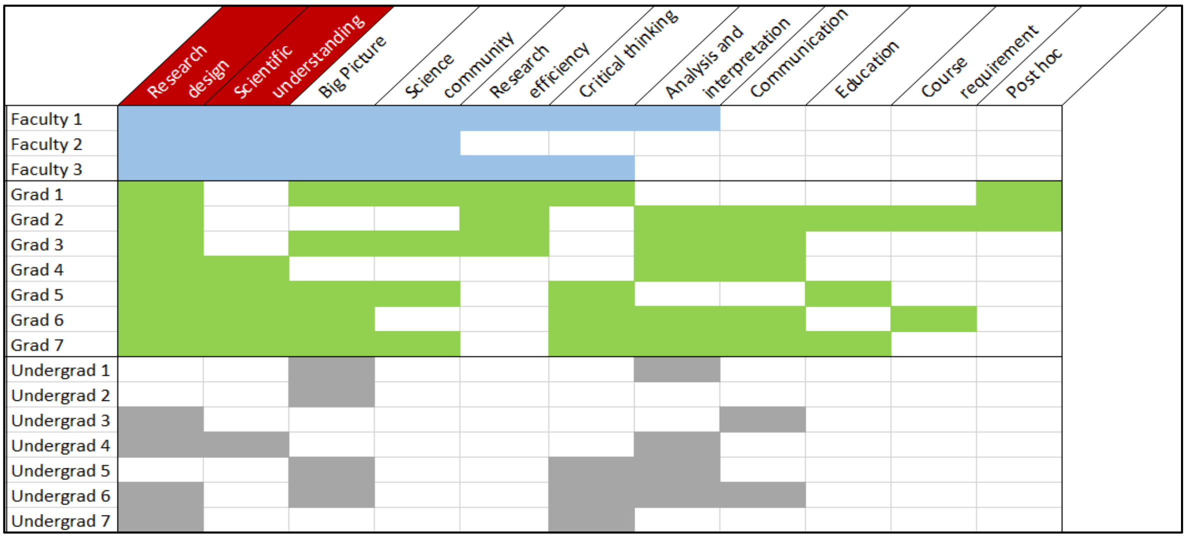


Figure 2. Participants' conceptions of the role of hypotheses and predictions in science. Red column headers indicate deductive codes. Highlighted cells indicate occurrence of a code in participant response.

Lastly, we see that faculty and graduate student groups identified similar challenges to student learning and opportunities to improve based on those, including 1) research experience, 2) explicitly teaching the concepts, 3) emphasizing student diligence towards these concepts, and 4) acknowledging that different schools of thought exist regarding how to define and use hypotheses and predictions (Fig. 4). Undergraduates, however, did not self-identify any challenges, which further strengthens our claim of a strong need to support undergraduate students in better understanding the nature and role of these fundamental concepts.

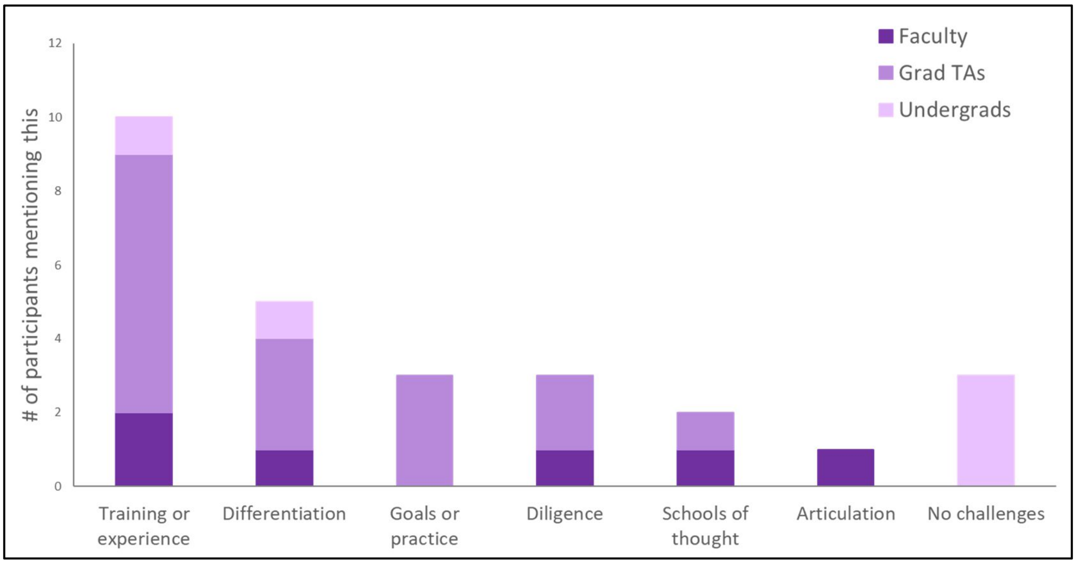


Figure 2. Challenges and opportunities for student learning identified by participants. Faculty n=3, graduate students n=7, undergraduate students n=7.

These findings suggest that both graduate TAs and undergraduate students may be relatively unfamiliar with the concept and application of a prediction, as compared to a hypothesis. This is similarly reflected in these two groups' diversity of conceptions regarding the relationship between hypotheses and predictions. Faculty, on the other hand, seem to have narrowly defined conceptions of the concept and application of predictions which align with the Popperian perspective. This is also mirrored in the consistent descriptions of the relationship between hypotheses and predictions. All participant groups had similarly diverse conceptions of hypotheses, which is notable considering the emphasis generally placed on scientific hypotheses in both research and teaching. Further analysis with more participants will be aimed at revealing patterns in this diversity that may exist between participant groups as well as within faculty members from different research sub-disciplines. Given the recent advances in methodologies and approaches to science (E.g.: data mining, computational and modelling techniques), it is interesting that the conceptions of inquiry expressed by all biology faculty in our limited sample still reflect the ideas originally put forth by Popper.

While there is continued emphasis on scientific hypotheses and, sometimes, predictions in prescribed guidelines for science education, this study is the first to explicitly investigate whether instructors' and students' understanding of these concepts is similar. Our preliminary findings serve to highlight the existence of variation in conceptions of scientific hypotheses among biology instructors and indicate divergence in conceptions of both hypotheses and predictions between instructors and students. These findings open up the discussion about the varied ways in which biologists think about hypotheses and predictions in relation to their own research as well as how they are framed for undergraduate students. A critical piece in our understanding of how best to support students in developing competence with these concepts and experimental design is to identify challenges that students face. Therefore, our study marks an essential first step in designing clearer and more consistent instruction and assessment regarding scientific inquiry for students of biology.

ACKNOWLEGMENTS

We would like to thank Dr. Elizabeth Suazo-Flores for her invaluable insights during the formative phase of this study and Sharleen Flowers for feedback and support during preparation for this conference.

REFERENCES

AAAS (2011). Vision and Change in Undergraduate Biology Education: A Call to Action. Washington, DC: AAAS. Available online at http://visionandchange.org/finalreport/.

Dasgupta, A. P., Anderson, T. R., & Pelaez, N. (2014). Development and validation of a rubric for diagnosing students' experimental design knowledge and difficulties. CBE Life Sciences Education, 13(2), 265–284. https://doi.org/10.1187/cbe.13-09-0192

Deane, T., Nomme, K., Jeffery, E., Pollock, C., & Birol, G. (2014). Development of the Biological Experimental Design Concept Inventory (BEDCI). CBE Life Sciences Education, 13(3), 540–551. https://doi.org/10.1187/cbe.13-11-0218

Kell, D. B., & Oliver, S. G. (2004). Here is the evidence, now what is the hypothesis? The complementary roles of inductive and hypothesis-driven science in the post-genomic era. BioEssays, 26(1), 99–105. https://doi.org/10.1002/bies.10385

Khodor, J., Halme, D. G., & Walker, G. C. (2004). A Hierarchical Biology Concept Framework: A Tool for Course Design. Cell Biology Education, 3(2), 111–121. https://doi.org/10.1187/cbe.03-10-0014

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. Journal of Research in Science Teaching, 39(6), 497–521. https://doi.org/10.1002/tea.10034

Lederman, N. G. (2006). Syntax Of Nature Of Science Within Inquiry And Science Instruction. In Flick L. B. & Lederman N. G. (Eds). Scientific Inquiry and Nature of Science (pp. 301–317). https://doi.org/10.1007/978-1-4020-5814-1_14

Mccomas, W. F., Clough, M. P., & Almazroa, H. (2005). The Nature of Science in Science Education. The Nature of Science in Science Education. https://doi.org/10.1007/0-306-47215-5

Pelaez, N., Gardner, S. M., Abraham, J. K., Hill, J. P., Hoover, M., Hurney, C., … Stevens, M. (2017). The Basic Competencies of Biological Experimentation: Concept-Skill Statements. PIBERG Instructional Innovation Materials, Paper 4(2017). Retrieved from http://docs.lib.purdue.edu/pibergiim/4

Popper, K. (1959). The Logic of Scientific Discovery. London, UK: Hutchinson & Co.

Ruxton, G. D., & Colegrave, N. (2011). Experimental design for the life sciences (2nd ed.) Oxford: Oxford University Press.

Saldaña, J. (2013). The coding manual for qualitative researchers (2nd ed.). London, UK: Sage.

Sirum, K., & Humburg, J. (2011). The Experimental Design Ability Test (EDAT) The Experimental Design Ability Test (EDAT). Bioscene, 37(1), 8–16.

Wilson, K. J., & Rigakos, B. (2016). Scientific process flowchart assessment (SPFA): A method for evaluating changes in understanding and visualization of the scientific process in a multidisciplinary student population. CBE Life Sciences Education, 15(4), 1–14. https://doi.org/10.1187/cbe.15-10-0212

Windschitl, M., Thompson, J., & Braaten, M. (2008). Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science investigations. Science Education, 92(5), 941–967. https://doi.org/10.1002/sce.20259

PROVIDING WAYS TO A HEALTHY DIET: PROFESSIONALIZATION IN THE CONTEXT OF SUSTAINABLE HEALTH EDUCATION IN ZANZIBAR

Saskia Tenberg[1], Doris Elster[2], Salum Seif Salum[3], Adam Rashid[4], Antje Hebestreit[5] and Sørge Kelm[6]

[1,2,6]University of Bremen, Bremen, Germany,

[5]Leibniz Institute for Prevention Research and Epidemiology - BIPS, Bremen, Germany,

[3,4]State University of Zanzibar, Mbweni, Zanzibar

The purpose of the interdisciplinary study Proshed (Professionalization in the context of sustainable health education in Zanzibar) is to improve the professional development of students at the School of Health and Medical Sciences (SHMS) from the State University of Zanzibar (SUZA). The aim is to find a suitable design for a lecture[19]*, that is likely to strengthen the students´ pedagogical content knowledge (PCK) with regard to sustainable health education. PCK includes the knowledge about conveying a certain content, that can be applied by patients in their everyday life. Therefore, a comprehensive concept and materials for a university course are developed and implemented in close cooperation of scientists and science educators of the University Bremen (UB), SUZA and Leibniz Institute for Prevention Research and Epidemiology – BIPS (BIPS). Following the paradigm of Design-Based Research (DBR) this explorative study is organized in cycles. This publication focuses on the first cycle, conducted in 2020. The pre-analysis is based on a first literature review and previous research activities within the project "Increased competencies for nutrition in Zanzibari health care" (MENTION). MENTION aimed to incorporate nutrition and health maintenance topics into the curriculum of the training programme for medical professionals in order to train medical experts' content wise and to provide current data on the Zanzibari society. This prior analysis results in a first design framework visualized in a Conjecture Map (CM). Based on the CM the initial cycle is led by the first Research Question (RQ): "What is a suitable design for lecture materials on sustainable health education for SHMS students?" Empirical data is drawn from interviews with 6 SHMS lecturers and a placemat on the method of Material-Based Writing, that was created during a lecturer-meeting. Based on those Design Principles (DP) for improved PCK - promoting materials and teaching concepts are deduced, the initial CM is specified and conclusions are drawn with regard to the practical implementation, design methodologies, design frameworks and further research steps. The findings indicate, that 1) building an own scientific-based and target-group oriented judgement with the method of material-based writing and 2) developing target-group oriented instructional strategies might be suitable mediating processes in order to promote the health and medical students´ PCK (design framework). Furthermore, the CM is seen as a useful tool to frame designs at the beginning of DBR-studies (design methodology). The specified CM is used to develop a first concrete Activity sequence, that allows research* ***on*** *the material and an evaluation of the first design approach.*

Keywords: Pedagogical Content Knowledge, Health Education, Design Based Research

[19] In agreement with the practitioners at the SHMS the term "lecture" is used to describe a university course for students, that enables student-student and student-teacher interaction and discussions.

CONTEXT AND RELEVANCE TO SCIENCE EDUCATION

Based on principles of Design Based Research (DBR), this study provides advantages for research AND practice (McKenney & Reeves, 2019) in the context of health education. Trainings on communication skills and sustainable health education are rare (Warde, Papadakos, Rodin, Salhia & Giuliani, 2018). These challenges are also faced by the SHMS (Nyangasa, Buck, Kelm, Sheikh & Hebestreit, 2019). After nutritional challenges have been identified (ebd.), a workshop was conducted at SHMS together with members from BIPS and UB in 2018 ending with the outlook of finding long-term solutions for better health outcomes by improving the medical students´ academical education. The resulting project MENTION aimed to incorporate nutrition and health maintenance topics into the curriculum of the training programme for medical professionals in order to train medical experts content wise and to provide current data on the Zanzibari society (Hebestreit, 2022). As part of MENTION, Proshed aims to provide innovative educational concepts and materials to promote students´ professional development. Beneath the practical output, DBR aims to further develop or use existing theories in new contexts (McKenney & Reeves, 2019). In this study the theoretical framework of PCK by Park and Oliver (2007) is transformed into the context of education for health and medical students and therefore aims to fill a gap between science education and medicine. PCK includes knowledge of how pedagogy can be effectively combined with content knowledge. It is thus knowledge of how a topic can be made understandable for learners (and possibly patients). While theory application and development are still background in the first cycle, first results in the areas of design frameworks and design methodologies (Burda-Zoyke, 2017) are generated. Design frameworks are given through first Design Principles (DP) and aim to provide concrete advice for a lecture design. Such DP stay hypothetical in a qualitative study (Bakker, 2018). Design methodologies can help researchers to design future DBR-studies in similar contexts. This publication provides an example of how Conjecture Maps (CMs, Sandoval, 2014) can be used for the pre-Analysis.

THEORETICAL BACKGROUND

Health Literacy (HL) comprises 'cognitive and social skills which determine the motivation and ability of individuals to gain access to, understand and use information in ways which promote and maintain good health (Nutbeam, 1998, p. 357). The lack of HL is a huge public health challenge (Sørensen, 2019). The way of communicating medical information can influence the patients´ HL (Bittner, 2016). Nevertheless, trainings to foster communication skills and sustainable health education for medical students are rare (Nyangasa et al., 2019; Warde et al., 2018). Approaches to promote the competence of transferring knowledge sustainably are common in science education, but not yet in medical education. Kuhnert (2011) suggests to use school pedagogy to improve communication skills of medical students. Surely, the concepts cannot just be copied into another context, but serve as a starting point in order to design environments, that enable health and medical students to provide sustainable health education. Park and Oliver (2007) provide an integrated concept of how to promote teachers PCK in science. From their perspective PCK is the "teachers'[doctors] understanding and enactment of how to help a group of students [patients] understand specific subject matter using multiple instructional strategies, representations, and assessments while working within the contextual, cultural, and social limitations in the learning environment."[20] (ebd., p. 246) Based on a structured literature review, they provide an inclusive PCK-model, that is used in this study as a basis for an adjusted concept for medical students. As Park and Oliver (2007) point out, the different elements of PCK are not distinct and influence each other. Therefore, aspects like Knowledge of Science Curriculum (knowing what information are important) or Knowledge Assessment (knowing how to asses if the learners / patients understand the given information) are automatically part of the research and the design and cannot be excluded. Nevertheless, initially the focus is put on Instructional Strategies and Student [in this context patient] Cognition, because their importance for PCK-promotion is highlighted in several studies (Herzog, 2019; Park & Chen, 2012). With regard to Instructional Strategies Magnusson, Krajcik and Borko (1999) distinguish between general approaches to instruction, that include inquiry-oriented instruction and specific strategies for teaching a particular topic (as cited in Park & Oliver, 2007, p. 266). Student [Patient] Cognition[21] is referring to typical arrows and misconceptions students [patients] might have on a specific topic (e.g., healthy nutrition, nutritional needs), their motivation, interest, need and diversity in ability (Park & Oliver, 2007).

PRE-ANALYSIS

The above described Workshop, which was held in 2018 with members of UB, SUZA and BIPS and aimed to develop first approaches for better health outcomes in the Zanzibari Community resulted into an internal report, that defined prioritized target groups, topics and suitable channels for Nutrition Education. Based on this report (Hebestreit & Alawy, 2018) a pre-analysis is done and framed in a Conjecture Map (CM). CMs are a "technique for conceptualizing design research […], a means of specifying theoretically salient features of a learning environment design and mapping out how they are predicted to work together to produce desired outcomes" (Sandoval, 2014, p.19). Further Sandoval (2014) describes this method as supportive tool for conceptualizing and carrying out research on learning environments and Reinmann (2014) adds that design assumptions can thus be made explicit and open to criticism (and therefore improvement). This is why the CM is chosen as a tool for framing a first concept, that has to be specified later in the research process. For this, main results of the Workshop report were outlined and allocated to the sub categories given by Sandoval, serving as first possible embodiment of main features of the lecture. The CM for the first design of a Proshed-lecture is given in figure 1.

[20] In brackets the hypothetical transmission into the context of Proshed.

[21] This term is used by Kuhnert (2011) and is considered more suitable for this context. Park and Oliver use the term "Knowledge of Students´ Understanding in Science".

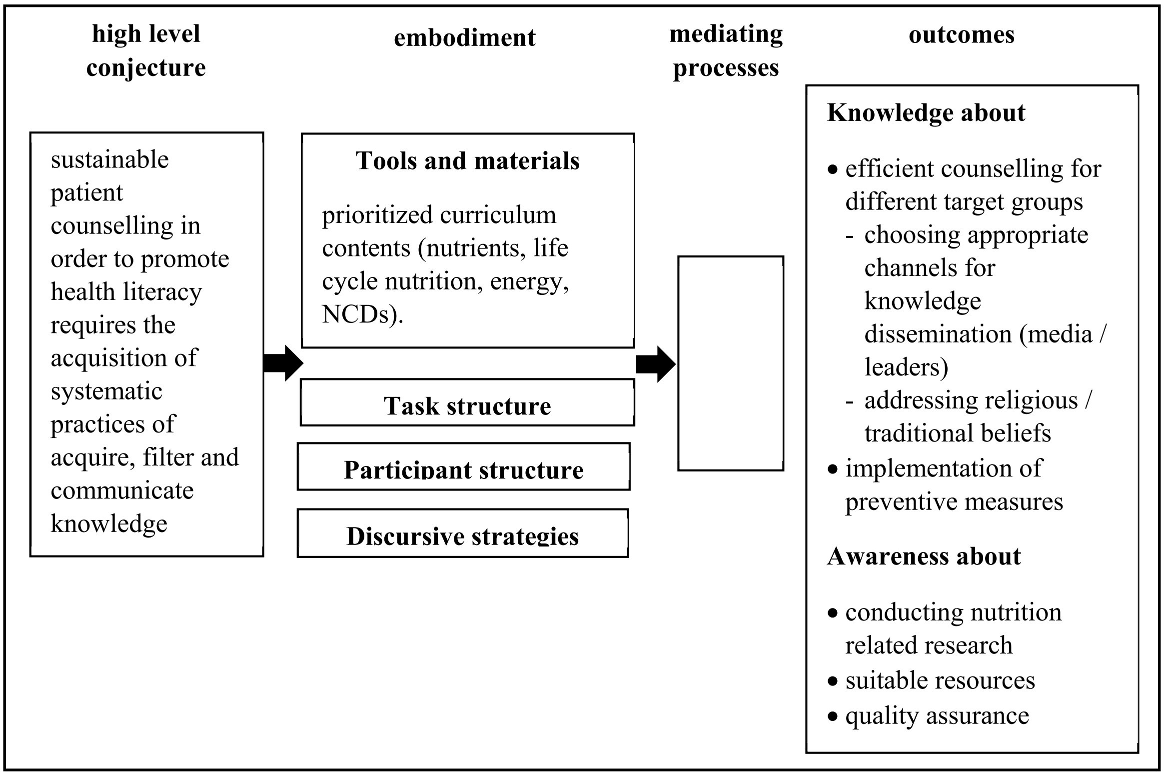


Figure 1. Conjecture Map based on the Pre-Analysis.

The high-level conjecture is a "theoretically principled idea of how to support some desired form of learning, articulated in general terms and at too high a level to determine design" (Sandoval, 2014, p.22). It is objectified in specific design features, that are captured in the embodiment. Tools and material of the embodiment should include contents that have been prioritized through the Workshop in 2018. Sandoval (2014) names three other elements within the embodiment: 1) Task structure (goals, criteria and standards of tasks), 2) Participant structure (way of participation of students and teachers in the tasks, roles and responsibilities) and 3) Discursive practices, that are referring to the "ways of talking" (ebd., p.22) within the lecture. Those still need to be more explored, as well as the Mediating processes - activities, that possibly produce intended outcomes (ebd.). Based on the MENTION Workshop Report (Hebestreit & Alawy, 2018), desired outcomes are an efficient counselling for different target groups, while using appropriate channels for knowledge dissemination and addressing religious and traditional beliefs, and preventive measures. In order to support these goals, it is seen as useful to raise awareness about conducting Nutrition related research, high qualitive resources and quality assurance. The CM, as a result of the Pre-Analysis, serves as a first and rough design framework. This framework is used to structure the first cycle within the DBR approach, that is divided into three sub-cycles: Analysis and Exploration, Design and Construction and Evaluation and Reflection. The research question (RQ) of the first cycle is directly building up on the CM and aims to provide a more detailed specification of the lecture design with the focus on the embodiment and mediating processes.

RESEARCH QUESTIONS (RQ)

The RQ1 "What is a suitable design for lecture materials on sustainable health education for SHMS students?" leads the first cycle. Lecture material includes information resources and material that structures tasks and enhances communication, e.g., working booklets. RQ1 focuses on research for material design, specifically on needs for a hypothetical design. Not only the sub-cycle Analysis / Exploration, but also Design / Construction and Evaluation / Reflection serve a needs and context analysis, that builds up on the MENTION Workshop and deepens its results with regard to embodiment and mediating processes. The sub-questions are shown in table 1. The leading question of the first sub-cycle is focusing on getting more specific perspectives on the needs of the SHMS. The leading questions within Design / Construction are building up on the results of the first sub-cycle and lead to a first design of activities, that can be evaluated in the following sub-cycle Evaluation / Reflection, that is not part of this publication.

Table 1. Core phases and sub-questions of RQ1.

What is a suitable design for lecture materials on sustainable health education for SHMS students?	
Core phase	Leading questions
Analysis / Exploration	What are the needs of SHMS lectures to improve the medical training with regard to sustainable health education?
Design / Construction	How should the lecture material be designed to address the needs of SHMS students and lecturers? What is known about the method of material-based writing and the development of a scientific based judgement?
Evaluation / Reflection	How is the first draft of the material developed received; What should be maintained and improved? (not included in this publication)

RESEARCH METHOD AND DESIGN

To answer RQ1, different qualitative methods are used. In Analysis / Exploration, based on a previous literature review, interviews with 6 lecturers of SHMS from different disciplines of the Medical Doctor and Environmental Health Program (e.g. biochemistry, nutrition) are conducted with the focus on needs identification. In Design / Construction first material is designed on the basis of a literature review on material-based writing (MBW). A document analysis of a placemat on the lecturers' perspective on MBW supplements the data. After the lecturers have been introduced to possible teaching methodologies, that might fit to intended outcomes (MBW, mysteries, video and business games, syndrome approach), the lecturers were asked to fill a placemat with the heading "How can we use the new impulses for the first semester of the new students?". The lecturers decided to focus on MBW, because it seemed most promising. They noted own ideas, which were commented by the other lecturers and lead to a summary of main elements, that need to be considered by implementing MBW. This summary is used as supplement data. In Evaluation / Reflection the implementation will be evaluated. This sub-cycle is not reported in this publication. The interviews are coded deductively based on the focus question of the sub-cycle and then coded inductively to identify emergent aspects. The categories are summarized in several steps, until core elements are determined. The core elements form the empirical part of the DP. Together with findings from literature, first DP for the skeleton design of the material are formed and afterwards summarized in pragmatic and specific principles (Bakker, 2018). For the document analysis (Placemat), the already summarized desired characteristics of MBW are compressed and thus serve as a supplement to the proposed establishment of MBW in the literature. Based on the findings DP are formulated and used for adjusting the CM.

FINDINGS AND DISCUSSION

In the following the pragmatic DP for the first two sub-cycles are given. For each sub-cycle one example of a specific DP is provided.

Table 2. Pragmatic and specific principles of cycle 1.

Core phase	Design principles
analysis and exploration	**Pragmatic Principles:** If you want to design a lecture for health and medical students on sustainable health education, you are advised to… 1) Provide a foundation with a holistic understanding of health and use an inquiry and student-oriented approach, that can be easily implemented by lecturers and students, includes diverse methods and materials and promotes community work. Test- and Evaluation strategies should be provided. (**foundations of the lecture**) 2) Focus on relevant topics, that have a strong influence on health and prioritized target groups for Nutrition Education. Consider different influences on health promoting decisions as well as interdisciplinary perspectives on nutrition. Provide scientific-based information and highlight the importance of efficient and targeted knowledge dissemination strategies. (**lecture contents**)
	Example of a specific principle of the pragmatic principle 1: Provide diverse methods and material, including e-learning material, because chances of e-learning possibilities for medical education in low- and middle-income countries are not yet fully utilized and explored and a high diversity of materials can support the adaptability to the learning environment. (Barteit et al.,2019)
design and construction	**Pragmatic Principles:** If you want to implement the material-based writing as methodology in a lecture for medical students on sustainable health education, you are advised to… 3) Chose a guided inquiry approach with a supporting learning environment with explanatory tools, and diverse materials – including e-learning materials and support students in finding a focus topic as well as evidence in scientific-based material for their own argumentation. For this introduce the correct use of scientific sources and provide tiered assistance before and within the writing process. (**methodology**) 4) Encourage self-regulated learning in groups with possibilities for peer exchange and support lecturers in their role of mentors. (**social form**) 5) Provide interdisciplinary content with a focus on local challenges and environments and strengthen the students in building their judgements based on scientific knowledge. (**content**)
	Example of a specific principle of the pragmatic principle 5: Focus on local challenges and environments by considering challenges and the availability of specific food types in Zanzibar, because health and nutrition behaviour is complex and influenced, among others, by environmental and personal determinants and the students can get the chance to gain specialist knowledge in this area [with support of MBW]. (Feilke, 2017; Schlüter, Vamos, Wacker & Welter., 2020; Sturm, 2017)

The deduced DP provide detailed information for the lecture design. Future results will merge with these and lead to more specific DP and in the end to concrete activity sequences. As a result of this initial study, general important features are outlined in order to provide a more detailed CM as a framework for future design processes. The adjusted CM is given in figure 2. The arrows indicate how design features are expected to work together. Each indicated relation is open to empirical investigation (Sandoval, 2014). Dotted arrows indicate less likely interrelations - because learning environments are complex and cannot be differentiated they all lead more or less to a pattern of change in outcomes (Salomon, 1996 as cited in Sandoval, 2014).

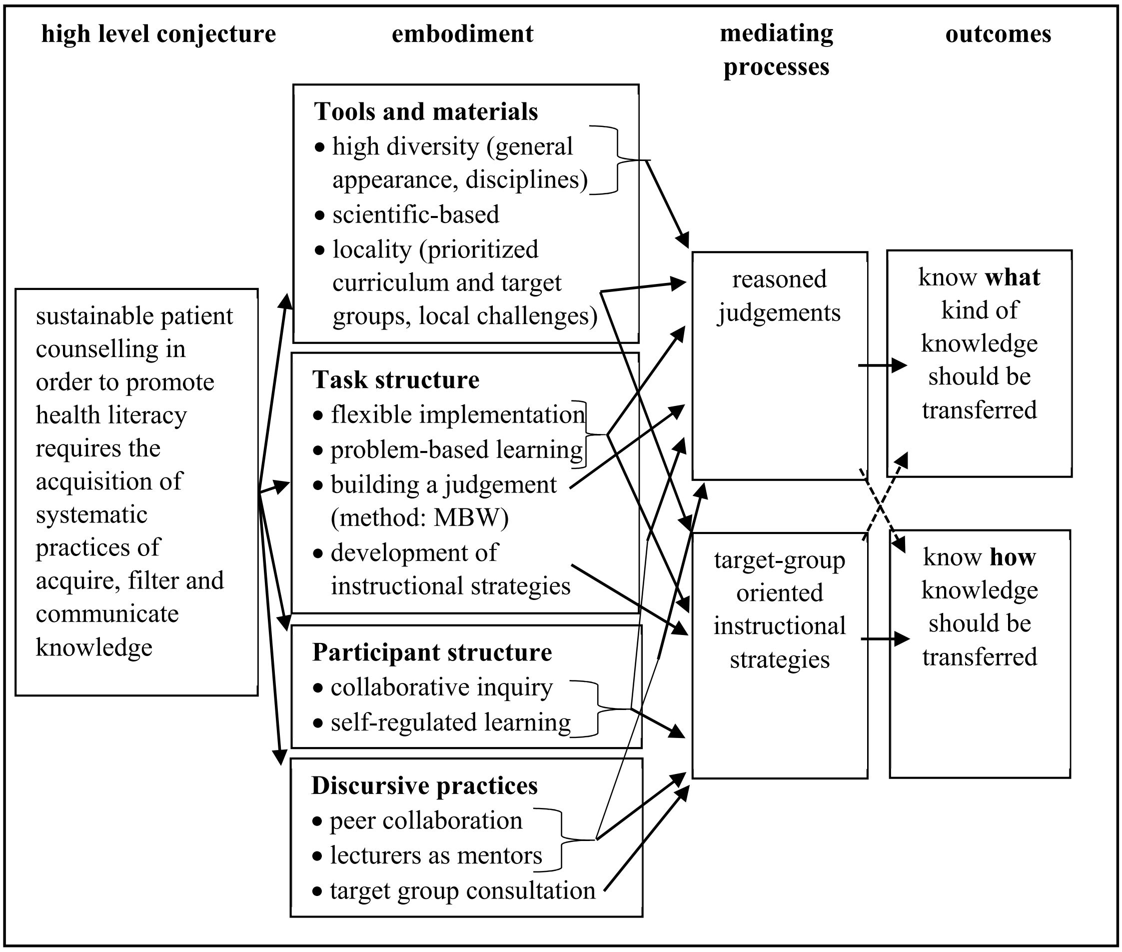


Figure 2. Adjusted Conjecture Map based on the Design Principles

Embodiment

Tools and materials should have a high diversity concerning their general objectives and reference to the nature of topics, that are taught at SHMS in order to strengthen the linkage between those disciplines. Furthermore, they should be scientific-based and referring to prioritized curriculum goals, that have been highlighted in the MENTION Workshop report (e.g., training on traditional believes with regard to nutritional needs). The tasks should be flexibly implementable to assure a sustained usage. Based on local challenges of the target groups, students should learn to build an own scientific judgement. It was discussed with workshop participants, that it might be supportive to develop instructional strategies in the lecture. Collaborative inquiry and self-regulated learning are seen as possible participant structures. This is not only a potential way of learning to transmit knowledge sustainably, but also an opportunity for the university to produce up-to-date and materials, that can support health outreach events. Argument-based inquiry, that includes constructing evidence-based claims and negotiations, seem to promote a sustainable implementation (Suh & Park, 2017). Self-regulated learning can support trainee doctors to develop self-efficacy, that enables them to use own resources and gain experience in complex decision making (Paes, Leat & Stewart, 2019). Three discursive practices are outlined. Students should collaborate with peers, while lecturers should function as mentors. Group work and guided learning might improve skills development in the area of evidence based practise and research knowledge translation (Hickman et al., 2018). This refers to the need of SHMS, that the lecture should be flexible implementable (mentoring is more flexible than settled lecture times). Thirdly target group consultations supplement the design of instructional strategies for patients, that can be used during these consultations. As underlined by Somporn, Ash and Walters (2018), community work has advantages for learners, patients and the health system.

Mediating Processes and Outcome

Recapturing the embodiment and the desired outcomes, possible mediating processes are identified. Health and medical students should arrive on a reasoned judgment with regard to specific target groups. Based on this, they should develop instructional strategies. These mediating processes intend to produce the outcome, that students learn what kind of knowledge is important for the target group and how it should be transferred in order to make it usable for the patient.

CONCLUSION

A conclusion can be drawn for the first implementation of the Proshed lecture as well as theoretical considerations on design frameworks and design methodologies (Burda-Zoyke, 2017).

Implications for practice and research

The CM is used for the first design of activity sequences, that can be conducted with students in order to evaluate the first design. The evaluation will lead to a new focus and RQ for the second cycle, which will emphasis research **on** material in order to improve the lecture concept.

Implications for design frameworks and design methodologies

Design frameworks: The DP presented above provide a more detailed framework for the lecture design, that aims to enhance health and medical students PCK. The DP serve as a basis for further specification of the design and will be combined with results of future cycles and so merge into new and more specific DP. Nevertheless, if you want to access all specific DP that feed the presented general DP, don´t hesitate to contact the first author.

Design methodologies: Using CMs as a tool to visualize and structure first design ideas supports the initial phase, when first ideas from practical experience and hints from literature, need to be structured in order to determine a suitable research question. Although possible influences are still highly hypothetical, the visualized interrelations can be used for planning in-depth analysis. Based on the experience of this study, the CM should be used as a tool for structuring initial ideas, visualizing current status and planning further steps in the research process. They should not be seen as rough settled concepts of the final design.

ACKNOWLEGMENTS

Sakina Alawy, Mustapha A. Masud, Othman H. Said and Chwukuma J. Okafor for on-going efforts to support Proshed. Proshed is financially supported by the project MENTION, the Horizon 2020 EU project RESBIOS (contract number 872146) and the Pagel-Programme of Deutscher Akademischer Austausch Dienst (DAAD, German Academic Exchange Service).

REFERENCES

Bakker, A. (2018). *Design Research in Education. A Practical Guide for Early Career Researchers*. Ebingdon: Roudledge.

Barteit, S., Guzek, D., Jahn, A., Bärnighausen, T., Jorge, M. M., & Neuhann, F. (2019). Evaluation of e-learning for medical education in low- and middle-income countries: A systematic review. *Computers and Education*, *145*(2020).

Bittner, J. (2016). *Vermittlung von Gesundheitskompetenz durch für Patienten verständliche medizinische Befunde* [Teaching health literacy through medical findings that patients can understand] (Doctoral dissertation, University of Cologne). Retreived from Publisso.

Burda-Zoyke, A. (2017). Design-Based Research in Der Berufs-Und Wirtschaftspädagogik-Rezeption Und Umsetzungsvarianten [Design-Based Research in the Professional and Economic Pedagogy - Reception and implementation variants]. In Tramm, t., Kremer, H. & Reinmann, G. (eds) *Entwicklungsbezogene (Praxis-)Forschung*, *33* (2017).

Feilke, H. (2017). Eine neue Aufgabe für das Fach Deutsch : Zusammenhänge herstellen - materialgestützt schreiben [A new task for the subject German : Making connections - writing based on material]. In *Didaktik Deutsch : Halbjahresschrift Für Die Didaktik Der Deutschen Sprache Und Literatur*, *22*, 4–11.

Hebestreit, A., & Alawy, S. (2018). *Report on Nutrition Education in Zanzibar: A needs assessment.* Internal source, available on requeset at Leibniz Institute of Prevention Research and Epicemiology - BIPS, hebestr@leibniz-bips.de. https://doi.org/10.13140/RG.2.2.25378.15041

Hebestreit, A. (2022). *Increased competencies for nutrition in Zanzibari health care*. Retreived from Leibniz Institute for Prevention Research and Epidemiology - BIPS: https://www.bips-institut.de/en/research/projects/detail-view.html?projID=736&cHash=87fe82dc8928770b1c3a38 533d088577

Herzog, S. (2019). *Analysis of content knowledge and pedagogical content knowledge of pre-service- chemistry teachers regarding the fundamental concept of structure -property-relations* (Doctoral Dissertation, Christian-Albrecht University of Kiel). Retreived from Semantic Scholar. (Corpus ID: 213485593)

Hickmann, L.D., DiGiacomo, M., Philips, J., Rao, A., Newton. P.J., Jackson, D. & Ferguson, C. (2018). Improving evidence based practice in postgraduate nursing programs: A systematic review. Bridging the evidence practice gap (BRIDGE project). *Nurse Education Today 63*(2018) 69-75.

Kuhnert, P. (2011). *Innovationen bei der Vermittlung kommunikativer Kompetenzen in der Medizinerausbildung. Eine Querschnittsstudie vor dem Hintergrund des Bologna-Prozesses* [Innovations in the teaching of communicative competences in medical. A cross-sectional study against the background of the Bologna Process](Doctoral Dissertation, University of Rostock). Retreived from University of Rostock.

Magnusson, S., Krajcik, L., & Borko, H. (1999). Nature, sources and development of pedagogical content knowledge. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (95–132). Dordrecht, The Netherlands: Kluwer.

McKenney, S. & Reeves, T. C. (2019). *Conducting Educational Design Research* (2nd ed.). London: Routledge.

Nutbeam, D. (1998). Health promotion glossary. *Health Promotion International*, *13*, 349–364.

Nyangasa, M. A., Buck, C., Kelm, S., Sheikh, M., & Hebestreit, A. (2019). Exploring food access and sociodemographic correlates of food consumption and food insecurity in Zanzibari households. *International Journal of Environmental Research and Public Health*, *16*(9). https://doi.org/10.3390/ijerph16091557

Paes, P., Leat, D., & Stewart, J. (2019). Complex decision making in medical training: key internal and external influences in developing practical wisdom. *Medical Education*, *53*(2), 165–174. https://doi.org/10.1111/medu.13767

Park, S., & Chen, Y. C. (2012). Mapping out the integration of the components of pedagogical content knowledge (PCK): Examples from high school biology classrooms. *Journal of Research in Science Teaching*, *49*(7), 922–941. https://doi.org/10.1002/tea.21022

Park, S. & Oliver, S. (2007). Revisiting the Conceptualisation of Pedagogical Content Knowledge (PCK): PCK as a Conceptual Tool to Understand Teachers as Professionals. *Res Sci Educ (2007), 38,* 261–284.doi: 10.1007/s11165-007-9049-6

Reinmann, G. (2014). Welchen Stellenwert hat die Entwicklung im Kontext von Design Research? Wie wird Entwicklung zu einem wissenschaftlichen Akt? [What is the significance of development in the context of design research? How does development become a scientific act?] In D. Euler & P. Sloane (eds.), *Design-based Research* (63-78). Zeitschrift für Berufs- und Wirtschaftspädagogik/Beiheft. Stuttgart: Steiner.

Salomon, G. (1996). Studying novel learning environments as patterns of change. In S. Vosniadou, E. De Corte, R. Glaser, & H. Mandl (Eds.), *International perspectives on the design of technology supported learning environments* (363–377). Mahwah, NJ: Erlbaum.

Sandoval, W. (2014). Conjecture Mapping: An Approach to Systematic Educational Design Research. *Journal of the Learning Sciences, 23*:1, 18-36, doi: 10.1080/10508406.2013.778204

Schlüter, K., Vamos, S., Wacker, C., & Welter, V. D. E. (2020). A conceptual model map on health and nutrition behavior (CMMHB/NB). *International Journal of Environmental Research and Public Health*, *17*(21), 1–12. https://doi.org/10.3390/ijerph17217829

Somporn, P., Ash, J., & Walters, L. (2018). Stakeholder views of rural community-based medical education: a narrative review of the international literature. *Medical Education, 52*, 791–802, doi: 10.1111/medu.13580

Sørensen, K. (2019). Defining health literacy: Exploring differences and commonalities. In *International Handbook of Health Literacy. Research, practice and policy across the lifespan* (5-20). Bristol, UK: Policy Press.

Sturm, A. (2017). Materialgestütztes Schreiben als schreibendes Lernen und fachspezifisches Arbeiten [Material-based writing as writing-based learning and subject-specific work]. *Didaktik Deutsch 22*, *43*, 19–15.

Suh, J. K., & Park, S. (2017). Exploring the relationship between pedagogical content knowledge (PCK) and sustainability of an innovative science teaching approach. *Teaching and Teacher Education*, *64*, 246–259. https://doi.org/10.1016/j.tate.2017.01.021

Warde, F., Papadakos, J., Papadakos, T., Rodin, D., Salhia, M., & Giuliani, M. (2018). Plain language communication as a priority competency for medical professionals in a globalized world. *Canadian Medical Education Journal*, *9*(2), 52-59. https://doi.org/10.36834/cmej.36848.

ESERA 2021
Fostering scientific citizenship in an uncertain world
30 Aug - 3 Sep 2021
Organised by University of Minho, Braga, Portugal

AN INNOVATIVE SHORT BLENDED FORMAT FOR TRAINING GRADUATE STUDENTS TO FOOD CHEMICAL SAFETY

Valérie Camel[1]

[1]Université Paris-Saclay, AgroParisTech, Palaiseau, France

A new innovative short blended teaching format is described here. It combines group activity in class based on a Thiagi frame game with production of graphical representations, and distance self-learning using open-access interactive digital resources organized in several successive modules. The total duration of the lesson is 7 hours, and its scientific content concerns the food chemical safety and related risk assessment. It is proposed in a Food Toxicology course of a second-year master degree academic program related to Toxicology and Environmental Health, with a majority of biological students as audience. Testing this new format with a cohort of students showed benefits: students were more engaged and encouraged to collaborate, learning from their peers through the production of graphical representations in class; in addition, success rates on the final exam increased. Because open-access resources were used to design this innovative teaching format, they could be used by colleagues interested in food chemical safety. Besides, the innovative format tested could be transposed to other teaching issues.

Keywords: Cooperative learning, Graphical Representations, ICT Enhanced Teaching and Learning

INTRODUCTION

Food safety is a major issue in the 21st century, as access to safe and nutritious food is crucial to sustain life, promote good health, and economic growth (Fung, Wang and Menon, 2018). Diet is recognized as a major contributor to exposure to several chemical hazards, with possible long-term deleterious effects on human populations. Several chronic diseases are suspected to be related to chemical contaminants in the food chain, such as obesity possibly related to endocrine disruptors. Future managers in the health or food sector need to be trained in food chemical safety, especially as several global factors (such as climate deregulation) are driving changes in food safety systems (Food and Agriculture Organization, 2006).

The academic context

The graduate program considered here is the second year of a Master's degree in *Toxicology and Environmental Health*, delivering 60 European Credits (EC). Food chemical safety is part of one-week *Food Toxicology* course (30h, 3EC) placed at the end of the first semester and offered as an option to students. Students taking this course come from a variety of backgrounds (biological background with little knowledge of chemistry; biological or chemical engineering students; pharmacy or medical students; professionals wishing to acquire new skills). A 6-hour course dedicated to food chemical safety is taught in this course with a traditional format of two 3-hour periods and primarily transmissive instruction. The learning objectives are fairly high in Bloom's taxonomy, with the final exam requiring critical thinking and risk calculations. A portion of the course time is devoted to an exercise to familiarize students with chemical risk assessment and to somewhat align the learning activity with the final exam, but the teaching method still needs improvement.

Theoretical considerations

The learning modalities were designed to provide "E-focused" blended learning along Jone's continuum (Chew, Jones and Turner, 2008), with interactive digital resources for distance learning and a student-centered pedagogical approach. Instructional techniques designed to have students work together in small, structured groups to achieve common goals (i.e. cooperative learning) were also considered, as group activities provide real opportunities for free discussion among students, with the potential to bring students into their zone of proximal development, thereby promoting learning and development (Eilks, Markic, Bäumer and Schanze, 2009). Tasks that require students to cooperate within the group are recommended (Gillies, 2016); producing a graphical representation seems to be an appealing option, as this task has been reported to improve scientific thinking (Fan, 2015).

A NEW STUDENT-CENTERED BLENDED FORMAT

The innovative blended format is designed to integrate the above theoretical considerations: (i) interactive digital media for distance self-learning; (ii) cooperative learning; and (iii) the production of graphic representations.

Session One: in-class cooperative learning (3h)

This classroom session is based on a cooperative Thiagi frame game focused on the issue of consumer risk assessment due to neoformed toxic compounds, immediately following a short instruction to impart the required knowledge about these types of food contaminants. Named "*Group grope*" (The Thiagi group, 2016), the game is played in several rounds with students divided into defined groups (they were asked to pick up a playing card as they entered the classroom, to be quickly divided into groups). First, each student is given four blank paper cards, and asked to write a kea idea on each card related to the main topics of the course issue (e.g., what data to acquire, collect and combine to assess risk). The teacher then collects and shuffles all the completed cards, before redistributing three cards to each student; the remaining cards are left visible on a table. Students may swap cards with those left on the table or with their peers, while keeping three cards in hand. Later, students work within their group to select only three of their cards to keep, and to draw a graphic representation detailing the content of those three cards to explain how to assess the risk to consumers of a particular example of neoformed toxic compounds in food. A short time is set aside at the end of the session to give oral feedback on the students' production, and to provide them with key knowledge relative to the risk assessment methodology.

Second session: distance self-learning on a case study (3h)

This session focuses on analytical methods for food chemical contaminants. The scientific content is available on the LMS platform, with distinct, short and successive modules (see illustration in **Figure 1**) offering different selected materials: texts and graphical representations, a short video, interactive digital educational resources in free access (specific pages of the CHIMACTIV website) and evaluation tests.

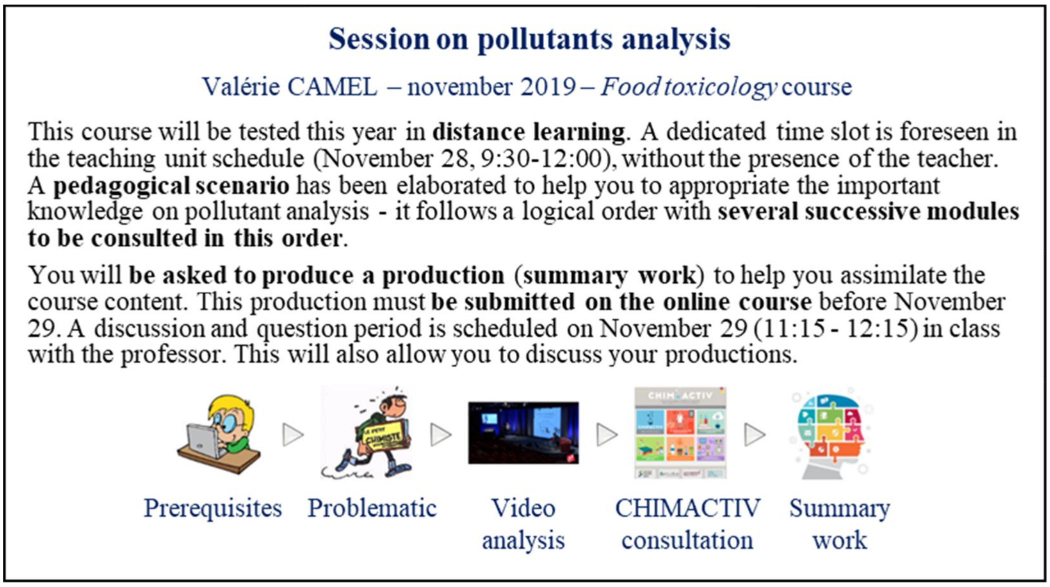


Figure 1. Home page of the asynchronous distance learning course offered on the LMS. (student view, originally in French and translated here into English; the modules images are interactive – by clicking on each module, dedicated pages and content are available).

Students are expected to consult these resources in autonomy and produce an individual assignment summarizing the highlights and ideas related to the course issue, with application to a case study on neoformed toxic compounds in foods. Instructions are given for completing this individual summary assignment, which must be submitted on the LMS platform by the last day of the course.

Third session: classroom exercises (1h)

This session is devoted to giving feedback on the students' individual productions and answering their questions. Key points relative to food regulations are also presented, before practicing on a risk assessment case study.

The learning scenario finally designed and proposed to the students is illustrated in **Figure 2**.

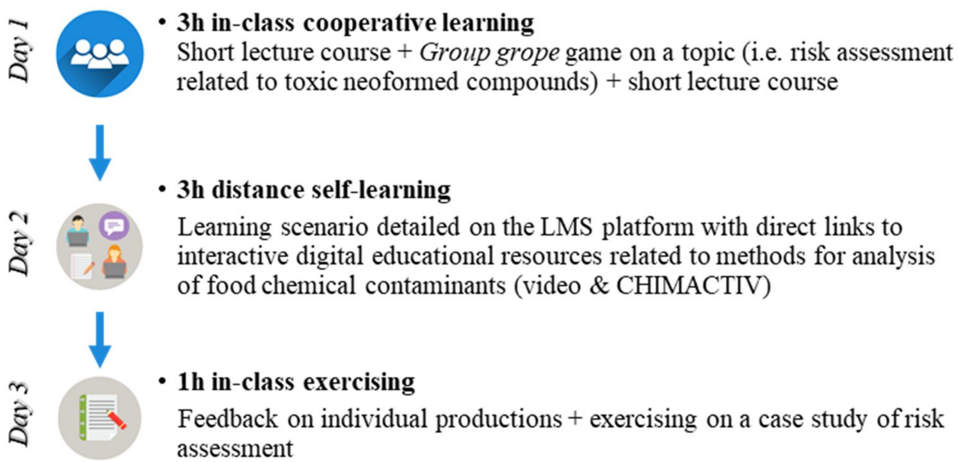


Figure 2. The proposed student learning scenario for the blended format.

RESULTS

Student views and academic performance

The detailed opinions, collected through an anonymous online questionnaire (18 respondents out of 18 students), were clearly favorable: 6 comments attributed the Thiagi frame game and the distance lesson as strenghts of the course, and 2 comments suggested adding more distance lessons. The remote session was cited 8 times as a weakness due to the long learning time (several students spent nearly double the time to view the resources). When considering student academic performance on the food chemical safety portion of the final exam for this *Food Toxicology* course, a comparison of the last three cohorts clearly shows the median pass rate improved from 42 to 52% with the innovative instructional format, as illustrated in **Figure 3**.

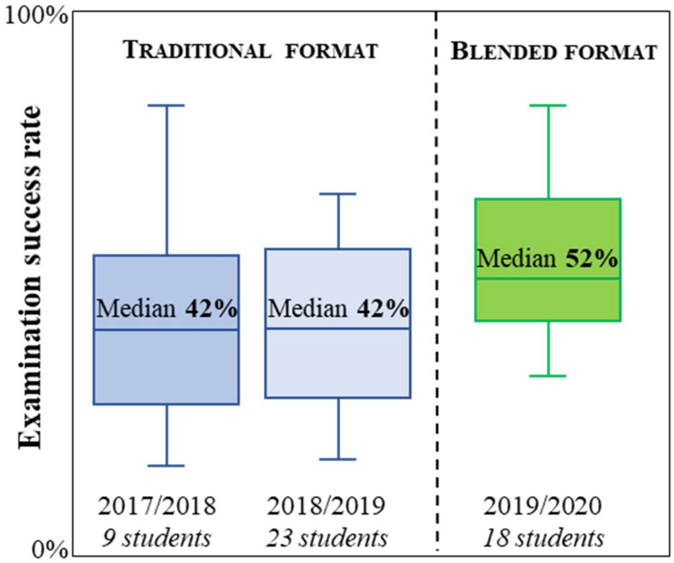


Figure 3. Pass rate on the food chemical safety portion of the final exam for three cohorts of students taught in traditional (2 cohorts) or blended (1 cohort) mode. (median values as well as minimum and maximum values are shown).

The teacher's perception and feeling

The positive attitude and commitment of the students during the Thiagi frame game was very impressive. They all made it through the session without taking a break, which would be unrealistic with transmissive teaching. This activity provided information about their prior knowledge, questions and learning difficulties for themselves and the teacher. Their final graphic representations were of high quality, as shown in **Figure 4**; the students were so proud that they took selfies of their group next to their poster.

For distance learning, even though the individual summary work was not concluded with a final grade, all students sent their production on time. The quality was somewhat uneven but quite satisfactory as shown in **Figure 5**, reflecting the time they spent consulting the digital resources and completing the assignment. With the exception of one student (who misunderstood the content), all students demonstrated their learning of the topic and thinking skills.

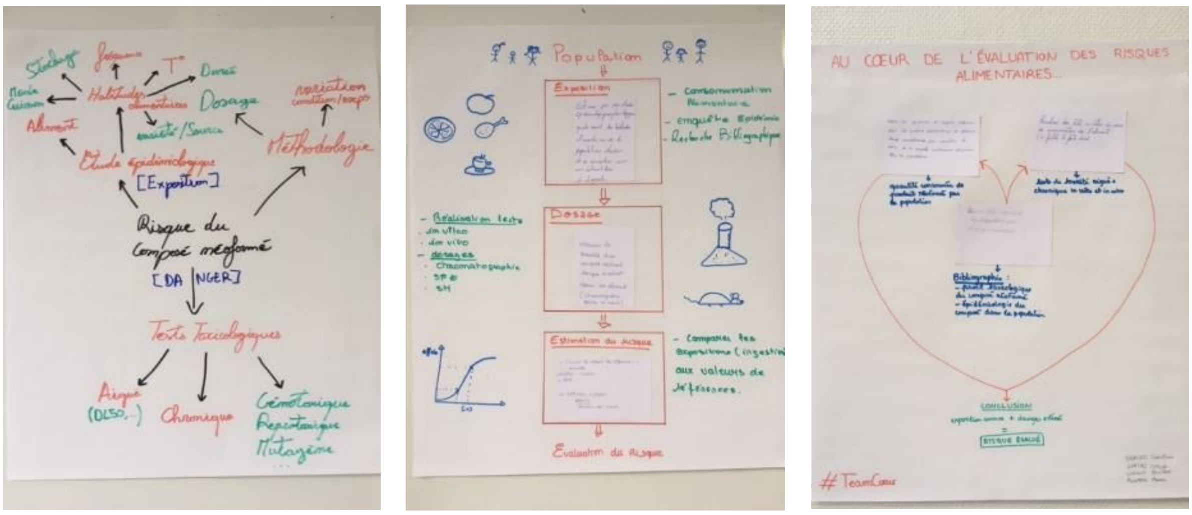


Figure 4. Classroom productions of student groups at the end of the Thiagi frame game.

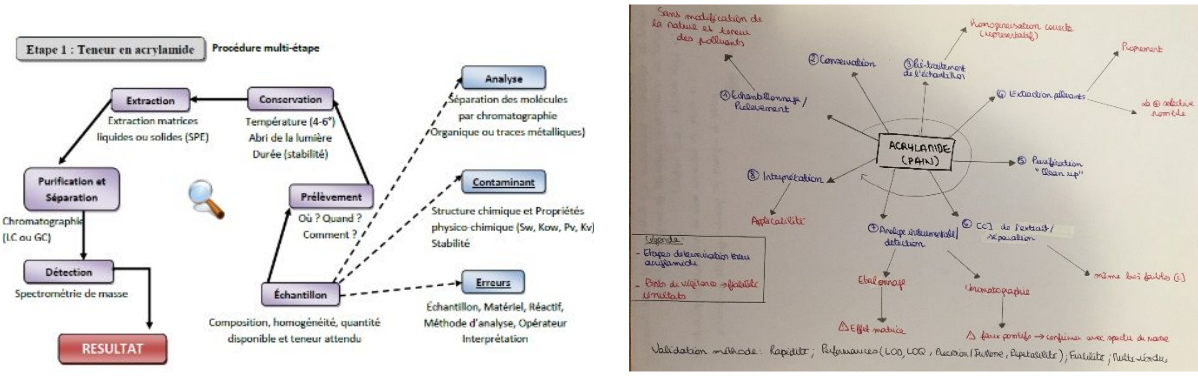


Figure 5. Examples of individual summaries completed in autonomy by students.

DISCUSSION AND CONCLUSIONS

Positive impacts on teaching and learning

The combination of an in-class cooperative work (with a graphic representation as output) and distance learning (with individual synthesis work) appears to be an innovative and effective short format for training master's biology students in food chemical safety. This student-centered format promotes student engagement in their learning, especially the cooperative learning activity as has been previously reported in higher education (Herrmann, 2013); student attitudes and engagement during this group activity are illustrated in **Figure 6**. Distance self-learning allows students to learn at their own pace with flexibility.

Feedback is improved for both the teacher (on the students' questioning and knowledge) and the learners (on their individual or collective productions); this is useful for quick remediation for both parties. This may have contributed to better learning compared to traditional teaching.

Figure 6. Groups of students debating which cards to select during the Thaigi frame game proposed in class.

A format easily transposed to other academic contexts

Due to their simplicity, Thiagi frame games offer interesting alternatives to the Jigsaw class frequently proposed as a cooperative activity (Eilks, Markic, Bäumer and Schanze, 2009; Gillies, 2016; Karacop & Doymus, 2013). Developed and used primarily for corporate training, these simple games are freely available on the web with a wide variety that allows one to choose the appropriate game based on the pedagogical intent. Most of the interactive digital resources used in this study are also freely available (Camel et al., 2020). Thus, this teaching format can be easily used or translated to other scientific issues by colleagues.

Some pitfalls and limitations

The amount of time spent preparing for the remote lesson is significant for the teacher. Another major constraint was to maintain a similar amount of time in the schedule so that the time spent on other lessons remains the same in the program. In the case of distance learning, time must be allowed for face-to-face discussions between the teacher and students, as the students are clearly in demand. It is also very important to take time at the beginning of the course to explain to students the pedagogical intent, and to carefully design the classroom and distance activities.

ACKNOWLEGMENTS

The author thanks the students who took the *Food Toxicology* course in 2019-2020 for their commitment and their agreement to be photographed. She also thanks *the Université Paris-Saclay for its funding related to the CHIMACTIV site (*IDEX funding awarded on the different calls for projects « *Former par le numérique* » 2014, « *Initiatives pédagogiques – Transformer* » 2016 and 2018).

REFERENCES

Eilks, I., Marjik, S., Bäumer, M., & Schanze, S. (2009). Cooperative learning in higher level chemistry education. In I. Eilks & B. Byers (Eds.), *Innovative methods of teaching and learning chemistry in higher education*. Cambridge, UK: Royal Society of Chemistry Publishing.

Camel V., Maillard M.-N., Piard J., Dumas C., Cladière M., Fitoussi G., Brun E., Billault I., Sicard-Roselli C. (2020). CHIMACTIV: an open-access website for student-centered learning in analytical chemistry. *Journal of Chemical Education, 97*(8), 2319-2326. doi:10.1021/acs.jchemed.0c00023

Chew, E., Jones, N., & Turner, D. (2008). Critical review of the blended learning models based on Maslow's and Vygotsky's educational theory. In J. Fong, R. Kwang & F.L. Wang (Eds.), *Hybrid learning and education*. ICHL 2008. Lecture notes in computer science, vol. 5169. Springer, Berlin, Heidelberg. doi: 10.1007/978-3-540-85170-7_4

CHIMACTIV: Interactive numerical educational resources for the analysis of complex media. *http://chimactiv.agroparistech.fr/en*

Fan, J.E. (2015). Drawing to learn: How producing graphical representations enhances scientific thinking. *Translational Issues in Psychological Science, 1*(2), 170-181. doi: 10.1037/tps0000037

Food and Agriculture Organization. (2006). *Food safety risk analysis - A guide for national food safety authorities*. Food and Agriculture Organization of the United Nations & World Health Organization (ISSN 0254-4725).

Fung, F., Wang, H.-S., & Menon, S. (2018). Food safety in the 21st century. *Biomedical Journal, 41*, 88-95. doi: 10.1016/j.bj.2018.03.003

Gillies, R.M. (2016). Cooperative learning: Review of research and practice. *Australian Journal of Teacher Education, 41*(3), 39-54. doi: 10.14221/ajte.2016v41n3.3

Karacop, A., & Doymus, K. (2013). Effects of Jigsaw cooperative learning and animation techniques on students' understanding of chemical bonding and their conceptions of the particulate nature of matter. *Journal of Science Education and Technology, 22*, 186-203. doi: 10.1007/s10956-012-9385-9

The Thiagi group. (2016). *Group Grope*. Retrieved from *http://www.thiagi.com/games/2016/6/21/july-cherchons-ensemble*