

# Chemistry Education Research and Practice

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## ARTICLE

**Does consulting open online educational resources to prepare for laboratory learning affect students' perception of their experimental self-efficacy and chemistry laboratory anxiety?**Valérie Camel,<sup>\*a</sup> Jonathan Piard,<sup>b</sup> Isabelle Billault<sup>c</sup> and Marie-Noëlle Maillard<sup>a</sup>Received 00th January 20xx,  
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Laboratory learning remains a pillar of analytical chemistry teaching, but students often arrive in the laboratory unprepared, especially being unaware of basic safety requirements or simple handling procedures. Consulting digital resources before the experimental sessions was reported to possibly improve their learning experience in the chemistry laboratory. Exploratory results suggested it improves students' experimental self-efficacy with subsequent anxiety reduction, but there is a need of further investigating this aspect. We conducted a semi-quantitative study focusing on these two interrelated constructs in the context of chemistry laboratory teaching. Six small cohorts were considered in several teaching contexts (undergraduate and graduate) across three institutions, and students were invited to consult the open online CHIMACTIV website. When learners consult targeted resources on this website before the experimental sessions, they perceive an increase of their self-efficacy and a reduction of their anxiety in the chemistry laboratory. For self-efficacy, the higher effect was observed on the "understanding concepts" dimension, followed by the dimension "sufficiency of resources". For anxiety, the higher benefit was noted for the dimension "using equipment and procedures" followed by "collecting data". Comparable results were obtained across the different cohorts. The correlation coefficients between dimensions confirm a positive and significant relationship: reductions in chemistry laboratory anxiety are associated with increases in experimental self-efficacy. The strongest correlation was observed between the anxiety dimension "using equipment and procedures" and the self-efficacy dimension "sufficiency of resources." These results suggest that students perceive online resources, such as the CHIMACTIV website, as contributing to their chemistry learning, particularly in relation to their self-efficacy and anxiety in laboratory contexts.

**Introduction**

"Analytical chemistry can be defined as the chemical metrological discipline that develops (R&D), optimizes, and uses tools and measurement processes in order to strengthen its capabilities to extract information – particularly to obtain quality (bio)chemical information about objects and systems of natural/artificial nature in order to fulfil specific needs or requirements with a view of facilitating grounded, timely decisions in scientific, technological, economic, and social areas" (Valcárcel, 2016, p. 15). In practice, this sub-discipline of chemistry is of crucial importance for other disciplines. However, time devoted to courses in analytical chemistry have been reduced in many universities, as recently exemplified in Sweden (Bergquist et al., 2023). Besides adapting to shorter courses,

teaching analytical chemistry faces other challenges: learners must acquire knowledge and understanding of analytical techniques and instrumentation, as well as the ability to process and interpret data acquired with different analytical methods (Masania et al., 2018). Laboratory instruction may promote the learning of certain theoretical concepts, and it is also very important in analytical chemistry to acquire practical skills (Hofstein, 2004). Laboratory sessions are also the best way to train students in the application of experimental procedures, the development of protocols and experimental methods, and the scientific approach (critical analysis, interpretation of results, scientific argumentation based on evidence), with a wide diversity of teacher instructions and tasks proposed to students depending on the learning objectives assigned to laboratory activities (Hofstein and Mamlök-Naaman, 2007). As underlined by Agustian and Seery (2017, p. 518), "laboratory education forms a unique and integral component of the chemistry curriculum".

Indeed, the laboratory offers a "more informal atmosphere and opportunities for more interaction among students and their teacher and peers can promote positive social interactions and a healthy learning environment conducive to meaningful inquiry and collaborative learning" (Hofstein and Lunetta, 2004, p.36). However,

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Supplementary Information available: Tables A.1 to A.7 and Figures A.1 to A.3 are given in the Appendix.



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it has been suggested that “meaningful learning in the laboratory would occur if students were given sufficient time and opportunities for interaction and reflection” (Hofstein and Lunetta, 2004, p.32). Yet, the time devoted to lab sessions in several curricula has decreased in recent years, mainly due to the associated costs, the lack of preparation time as well as stricter safety regulations (Boesdorfer and Livermore, 2018; Chalupa and Nesmerak, 2023). In the meantime, unprepared students arriving in the laboratory often suffer from cognitive overload (as laboratory is considered a complex learning environment); this leads to task execution as “cookbook” following the laboratory guide, without making connections between experimental work and the theoretical concepts (Jolley et al., 2016). In addition, unprepared students may present a low self-efficacy belief and/or some anxiety relative to the chemistry lab (especially if they have minor previous laboratory experience due to unfamiliar learning environment, handling of chemical hazards and expensive instruments, as well as acquirement of data within a limited time frame), both of which hinder learning. Thus, a recent study reported students’ anxiety decrease after having experienced chemistry laboratory, possibly due to development of security and self-confidence in manipulating hazardous chemicals, using equipment, executing laboratory procedures, collecting data and managing their time in the laboratory (Avila-Ascanio and Gualdrón-Pinto, 2022).

In such a context, particular attention should be paid to the educational content and activities offered to students in order to prepare them for chemistry laboratory classes. As recently reviewed, several pre-laboratory activities have been proposed in chemistry curricula to improve laboratory learning experience (Agustian and Seery, 2017). Such activities differ depending on their learning objectives: (i) mainly lectures, quizzes and discussion to introduce chemical concepts; (ii) technique videos, interactive simulations, mental preparation (related to the experiments) or safety information to introduce laboratory techniques; (iii) the pre-cited activities for addressing affective dimensions that are important during the laboratory sessions (namely student confidence and motivation).

In the past decade, the introduction of digital tools (videos, simulations, online quizzes, virtual lab, etc.) permitted the production of a broad coverage of resources in chemistry. Efforts have been put on addressing the engaging character of these resources, in order to favor their use by the students for learning. As an illustration, online interactive tools were reported to be freely chosen by the majority of 252 first-year students enrolled in a general chemistry laboratory course in a Uruguayan public university (Veiga et al., 2019). In the same line, in the context of an analytical chemistry course in second year of an Australian university, students’ attitudes were reported to be very positive toward online material (especially prelab quizzes) since digital resources provide a “flexible learning platform” that enables students to work independently and at their own pace (Jolley et al., 2016).

Yet, whether such digital resources have a beneficial impact on learning by enhancing experimental self-efficacy and reducing chemistry laboratory anxiety has been rarely explored until now. In particular, in the field of analytical chemistry where three major open educational websites are currently available (the ChemCollective site - <https://chemcollective.org/>, the Analytical

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Sciences Digital Library - <https://asdlb.org/>, and our CHIMACTIV website - <https://chimactiv.agroparistech.fr/en/>), there is a lack of studies assessing the benefit of using these open online educational resources as support for pre-laboratory activities in order to improve students’ self-efficacy and reduce their anxiety, with a view of favouring learning in chemistry laboratories. Since, from our point of view, CHIMACTIV is the sole website that offers broad coverage of the analytical chemistry field and bilingual resources, this website will serve as a model to evaluate this benefit.

## Discussion of the literature

### Laboratory work as a pillar of analytical chemistry education

Experimental sessions are recognized as important for teaching chemistry. “Doing science in the chemistry laboratory is highlighted as a key characteristic of laboratory work that distinguishes it from other pedagogies in higher education, such as lectures and tutorials. It largely defines a chemist and, as such, is deeply ingrained in their professional identity.” (Agustian, 2025, p. 218). As a consequence, the American Chemical Society international guidelines for undergraduate chemistry programs “require that students have 350h of lab experiences beyond general (or introductory) chemistry”; in addition, these guidelines recommend “that the majority of these lab activities occur in person” to ensure students get the required experience and skills (Brooks and Lawal, 2025, p. 379).

Several learning objectives may be assigned to these sessions as mentioned previously, such as a better understanding of the theoretical concepts, acquiring practical skills and/or scientific skills (such as obtaining data and being faced with variability of measurements), or developing transferable skills (such as team work, team management or problem-solving) (Seery, 2020; Agustian et al., 2022). A progressive laboratory curriculum is recommended across the entire degree (first-year to fifth-year of university) so that practical and cognitive tasks are more demanding as the students pass a new year, and the affective domain (such as self-efficacy and laboratory anxiety) deserves also consideration (Agustian, 2025).

Classically in chemistry education four laboratory instruction styles have been proposed: expository, open inquiry (or inquiry), guided inquiry (or discovery) and problem-based (Domin, 1999). They all differ considering the outcome, approach and procedure. Expository, guided inquiry, and problem-based activities all have predetermined outcomes, while outcomes are undetermined with open inquiry-based activities. Considering the approach, expository and problem-based activities typically follow a deductive approach (students apply a general principle toward understanding a specific phenomenon), while guided inquiry and open inquiry-based activities are inductive (by observing particular instances, students derive the general principle). For the procedure to be followed in the laboratory, it is either provided to the students (expository and guided inquiry-based activities) or designed by the students themselves (open inquiry and problem-based activities). A more detailed characterization was proposed few years later, with five levels of inquiry based on six characteristics (problem/question, theory/background, procedures/design, results analysis, results communication, conclusions) and the level of student independence associated with each: confirmation, structured inquiry, guided inquiry, open inquiry

and authentic inquiry (Buck et al., 2008). The laboratory offers a unique opportunity for learning by inquiry (Hofstein and Lunetta, 2004).

Several authors report a beneficial of inquiry-based instruction modes for chemistry learning in high education. As an illustration, in a mixed-methods (questionnaire plus interviews) research study, Matakaka and Kowalske (2015) reported that undergraduate students who participated in problem-based learning laboratory units improved their self-efficacy belief in chemistry, and that this improvement was stable and long-lasting. In the field of analytical chemistry education, Madybekova et al. (2026) reported that, besides enhancing competency development, problem-based learning (with guided-inquiry tasks for the lab work) positively influenced students' attitudes toward analytical chemistry.

However, inquiry-based activities are time-consuming, and this time may not be available in chemistry curricula (Ural, 2016). In addition, as underlined by Bruck and Towns (2009) "underprepared students have experienced negative results when attempting inquiry-based activities"; these authors recommended that "students must possess appropriate prior knowledge of the topic to be investigated in laboratory" and that they "must also possess sufficient knowledge of the procedures and techniques for the laboratory and be able to use them".

In the case of analytical chemistry education, experimental sessions are important since "the ability to make reliable and accurate measurements by using the analytical method is an essential part of the undergraduate curriculum" (American Chemical Society, undated). As a consequence, teachers "should consider how to effectively combine classroom and laboratory instruction to meet learning goals" (Kovarik, 2025). However, laboratory sessions may be in practice difficult to implement in the academic programs for high level degrees (such as master of science), as several required instruments may be unavailable nor operational (e.g. liquid chromatography) due to instrument cost, failure or obsolescence. Indeed, obtaining and maintaining instrumentation was the challenge most identified by 322 instructors of undergraduate analytical chemistry surveyed in 2021 under the auspices of the Division of Analytical Chemistry of the American Chemical Society (Kovarik, 2025). When laboratory sessions are proposed, their duration in the curricula remain limited due to expensive costs as compared to digital tool alternatives (Achuthan and Murali, 2015; Kennepohl, 2021), with time spent in chemistry laboratories decreasing over years (Reid and Shah, 2007). Indeed "teaching laboratories are labor intensive (prep staff, instructional faculty, graduate teaching assistants) and costly (specialized classroom space, breakable equipment, instrumentation, consumable chemicals that cannot be reused each semester, waste disposal costs, salaries and tuition of graduate student instructors...). And these costs only increase as we move from introductory laboratory courses for the masses to specialized laboratory courses for the (relatively) small number of chemistry majors." (Bretz, 2009, p. 194). By way of consequence, the learning objectives of these laboratory sessions should be carefully assigned. In addition, preparation of these sessions is mandatory since "the value of laboratory work must be severely limited by the students' unpreparedness" (Reid and Shah, 2007, p. 177), especially for students who have limited experience of chemistry laboratory. For that purpose, digital

resources have faced growing interest in recent years, especially since the Covid-19 pandemic, as they offer interactive formats that sound promising as detailed below.

### Preparing for lab sessions with interactive digital resources

Providing theory and procedural guidance in an interactive way using digital resources should be helpful to students, avoiding high cognitive load upon arrival in the chemistry laboratory (Washbourn, 2024). That way students should be more performant in the laboratory. In addition, preparing lab sessions is also intended to enable students to feel more confident about lab work and/or to reduce students' anxiety once in the chemistry laboratory (Agustian and Seery, 2017; Teo et al., 2014). In particular, in analytical chemistry education, the use of e-quizzes combined with instructional videos for preparing lab sessions was reported to increase the students' feeling of preparedness and to obtain a positive learning experience from the laboratories (Jolley et al., 2016). Instructional videos were also found successful for upper-division chemistry laboratory courses characterized by an instrument intensive nature of the experiments: students watched the videos to become more prepared for the lab sessions, with subsequent gain in autonomy as they acquired more familiarity with the instruments (Schmidt-McCormack et al., 2017). The use of a virtual laboratory experiment coordinated with practical laboratory assignments in a blended learning scenario was also found as a valuable teaching and student engagement tool (Bortnik et al., 2017).

It was also reported significantly less technique incidents in the lab when students prepared the session with online digital resources as compared to prelab preparation using a traditional laboratory script, as well as improvement in manipulations; this was aligned with students feeling more confident in attempting to conduct activities in the lab when they had used the online learning resource as a preparative tool (Sarmouk et al., 2019).

In another study within a context of *Bachelor of Science*, Kolil et al. (2020) reported that most students surveyed (total of 1225 students) expressed low or below average self-efficacy scores before performing experiments in chemistry lab sessions. They also gave evidence that the use of simulations and animations (thanks to a dedicated virtual laboratory platform) significantly improved the experimental self-efficacy of their students.

Interestingly, Soulé et al. (2025) have recently reported the beneficial use of a virtual lab as a teaching material optional for 168 first-year students enrolled in a chemistry introductory course to prepare experimental sessions; 162 (96.4%) students declared having used the platform. Among users, "a significant majority (> 80%) reported that the platform helped them become familiar with the lab and reduced their anxiety about the laboratory course" (Soulé et al., 2025, p. 351). This virtual lab, ChemView360, was based on 360° pictures of the laboratory with interactive markers on hot spots and also short videos highlighting the experimental procedures and outcomes.

In another study, Gungor et al. (2022) tested the impact of virtual reality (VR) on self-efficacy, interest, self-concept and laboratory anxiety of 17 undergraduate (2<sup>nd</sup> and 3<sup>rd</sup> year) pharmacy students from a northern European university, enrolled in a three-week organic chemistry course (organized with two weeks of theoretical

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courses followed by one week of laboratory sessions). After collecting students' feedbacks thanks to a questionnaire exploring the four constructs completed by semi-structured interviews, at the end of a course combining VR and lab sessions, they noted that some "students reported an increase in positive association confidence in the lab, and a decrease in laboratory anxiety" (Gungor et al, 2022, p. 5), possibly linked to preparation of lab sessions using VR.

Consequently, several studies report the beneficial impact of preparing chemical laboratory sessions upon consulting digital resources. These exploratory results suggest enhancement of students' experimental self-efficacy with subsequent anxiety reduction as detailed above. For example, Dalgarno et al. (2012) reported that undergraduate chemistry students who used a virtual laboratory for preparing chemistry laboratory sessions were generally positive about its value in contributing to their confidence and reducing their anxiety about practical work.

Yet, there is a need of further investigating this aspect, and this is the focus of our study, which aims to assess the positive impact of consulting targeted digital resources in preparation of practical work on enhancing self-efficacy and reducing anxiety.

### The CHIMACTIV website as a support for chemistry learning

We decided to provide students with appropriate assets related to analytical chemistry, so that they have the opportunity to train themselves before the laboratory sessions. Thus, few years ago, we created the CHIMACTIV website. It provides open interactive digital resources to support chemistry learning in both laboratory and theoretical contexts (Camel et al., 2020); all these resources are under the international Creative Common license BY-NC-ND (Attribution-NonCommercial-NoDerivatives) 4.0. The website content spans four main areas: chemistry concepts, methodology, laboratory techniques, and safety considerations. The resources include videos (text transcripts with timelines are available as recommended by Schmidt-McCormack et al., 2017), interactive diagrams, quizzes, games and exercises designed to engage students, reduce cognitive load, and facilitate learning before, during, and after laboratory sessions. Their open access and digital responsiveness make them easily available on any medium (computer, tablet, or smartphone), providing "easy-to-access"

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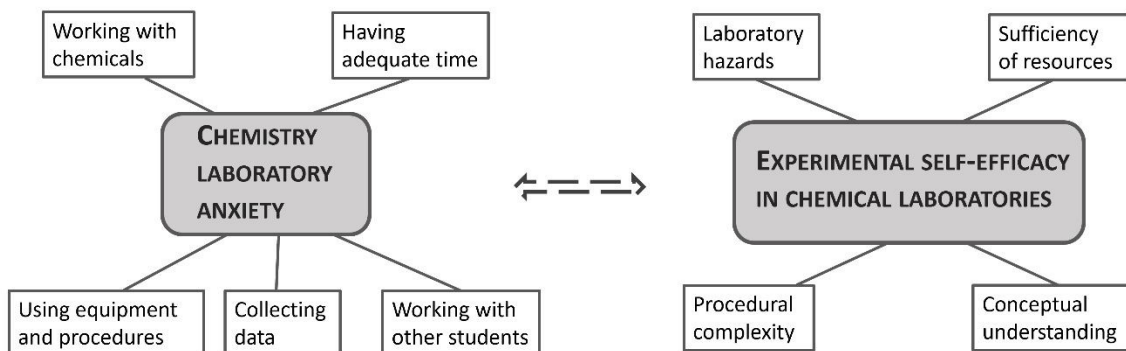
consultation out-of-class in remote environments (such as transports) as well as in-class in chemistry labs, it was previously reported to be valuable for third-year chemistry students, who actively watched lab videos during lab sessions when they were viewable on a portable electronic device, to gain assistance for using advanced chemical laboratory techniques and instrumentation (Loughlin and Cresswell, 2021). Teachers may easily direct their students to targeted CHIMACTIV resources, particularly before experimental sessions, so that they can review safety requirements (Camel et al., 2021), familiarise themselves with the procedures to be used, and reflect on the experimental plan to be implemented. Such resources are particularly useful for teachers that intend to flip their laboratory sessions as key concepts related to analytical chemistry are covered and pre-laboratory activities are easily designed by targeting the corresponding resources.

By integrating multiple modalities of learning, the CHIMACTIV resources aim to promote active engagement, self-directed preparation, and deeper understanding of experimental procedures. Such tools align with research showing that pre-laboratory preparation and interactive resources can enhance students' self-efficacy, reduce anxiety, and improve overall engagement in laboratory learning (Agustian and Seery, 2017).

### Theoretical framework

"Distractions and risks may increase anxiety, which can reduce efficacy through thoughts of failure, physiological manifestations of stress, and the reduction of coping mechanisms" (Gist and Mitchell, 1992, p. 194). It is now well documented that, in chemistry education, students may develop anxiety towards laboratory sessions due to several factors, such as handling chemicals, using unfamiliar and expensive equipment, improper experimentation, lack of concept understanding or lack of knowledge related to safety procedures (Kolil et al. 2020; Gungor et al., 2022). The limited duration of the experimental sessions also contributes to their anxiety, as they often fear that they will not have enough time to complete their experiments.

Whenever present, this chemistry laboratory anxiety will negatively affect students' experimental self-efficacy during lab sessions, with possible adverse impacts on learning and performance. The theoretical framework used in this study is illustrated in **Figure 1** and detailed below.



information. This feature is particularly convenient for enabling  
**Figure 1:** the theoretical framework considered in this work.

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**Experimental self-efficacy**

Self-efficacy was introduced as an important concept by Bandura (1977). It may be defined as "a person's judgement of their ability to organise and use the various activities necessary to accomplish a task" (Bouffard-Bouchard and Pinard, 1988, p. 411). This judgement, highly dependent on the situation and its context, is well-recognized as an important determinant of academic outcomes, since it is described as "the beliefs of individuals about their abilities to successfully complete an action" (Kolil et al., 2020, p. 350). Self-efficacy is considered a dynamic construct, since the person judgement to perform efficiently a specific task may change over time, especially as "new information and experience are acquired" (Gist and Mitchell, 1992, p. 184).

Science self-efficacy was found to positively predict science achievement at both student- and classroom- levels (Burns et al., 2021). As self-efficacy is dependent on the domain considered (Artino, 2012), we focused our bibliographic research on applications of this construct to chemistry teaching, focusing on teaching with experimental sessions as students' self-efficacy belief might be different in lab sessions or during theoretical courses. We were particularly interested in investigating "experimental self-efficacy", previously defined as "the belief in one's ability to successfully execute action and observation in a controlled way within an experimental environment to achieve its outcomes" (Kolil et al., 2020, p. 3).

We found only two questionnaires detailed in the literature and already validated for exploring self-efficacy belief in the context of chemistry learning during experimental sessions. The first one was developed and validated by Alkan (2016) for high school students in Ankara (Turkey), and with two dimensions considered (psychomotor and cognitive self-efficacy), each being explored through 7 questions. The second questionnaire was developed and validated by Kolil et al. (2020) in a teaching context rather close to ours, since they considered undergraduate students (1225 as total number) from different institutions (in India) where laboratory classes were part of the chemistry teaching programs. They identified factors causing anxiety related to chemistry laboratory based on an open-ended online survey sent to all students, and they further validated the four proposed main categorized thanks to a survey conducted amongst 125 students (in a *Bachelor of Science* program) with a set of four typical experiments (such as acid-base titration). Then they developed questions related to each factor, that were verified by experts from chemistry as well as educational psychology. Their final questionnaire includes four dimensions: conceptual understanding (it refers to the student's knowledge of the theory behind the experiments, and includes the understanding of the concepts and principles being tested in the experiments), procedural complexity (this is related to the difficulties faced by students in calculating arithmetically, for example for preparing diluted solutions, as well as in executing the experiment steps, and it includes the understanding of the required calculations and steps), laboratory hazards (it is related to potential accidents such as accidentally breaking apparatus or spilling chemicals), sufficiency of resources (it refers to the adequacy of apparatus such as beakers or pipettes, instruments such as flame photometer, and instructors to perform the experiments) (Kolil et al. 2023). The first two dimensions refer to

cognitive laboratory activities and the last two to physical laboratory activities (Kolil et al., 2020; Kolil et al., 2023). Each of these four dimensions was explored with three questions, thus leading to the "Experimental self-efficacy (ESE)" questionnaire composed of 12 items. This ESE questionnaire was further tested and revalidated by Kolil et al. (2023) on 1123 students from chemistry, physics and biology over 26 institutions in India using confirmatory factor analysis.

We decided to choose the ESE questionnaire for assessing our students' chemistry laboratory self-efficacy belief, due to the high level of similarity with our context.

**Chemistry laboratory anxiety**

Anxiety may be defined as "an unpleasant (usually temporary) emotional state characterised by feelings of tension, apprehension, nervousness and worry" (Hellemans, 2004, p. 2). An anxious student "will be more easily distracted, suffer from negative cognitive interference, and this state could have a negative impact on the academic performance" (Danthony, 2020, p. 14).

It is well-documented that most students are anxious once in the laboratory since they are not very familiar with this environment. This is particularly crucial for chemical laboratory due to the use of chemicals and the presence of several hazards, as well as other disturbances such as noise and smells (Stone and Arenas, 2025). As an illustration, 43 undergraduate students (out of 55) enrolled in a Chemistry program in an Australian university declared feeling anxious about the laboratory sessions (Dalgarno et al. 2012). The limited time devoted to lab sessions is also a major factor of anxiety for students since they are afraid of not being able to perform the experiments and acquire their data (Sharpe, 2012). The cognitive tasks associated with lab sessions are also a major source of anxiety for students (Rummey et al., 2019; Sharpe, 2012).

Several questionnaires exploring anxiety related to chemistry laboratory were reported in the literature, with few of them being readily available.

The Laboratory Anxiety Questionnaire (LAQ) was developed for undergraduate students in a Turkish university (Acar Sesen and Mutlu, 2014). It is composed of 20 items covering four aspects of experimental work (using chemicals, laboratory materials and equipment, laboratory accidents, making mistakes during experiment process). An adaptation was reported and tested with students from a *Bachelor of Science* Food Technology, that is composed of 20 items covering the same aspects (handling chemicals, laboratory materials and equipment, laboratory accidents, committing mistakes during the experiment) (Damo et al., 2020). The items are formulated as statements rather than questions, and they are mainly concerned with lab hazards.

The Chemistry Laboratory Anxiety Instrument (CLAI), also cited as the Chemistry Laboratory Anxiety Scale (CLAS), was developed for measuring college students' anxieties in chemistry laboratories in the United States (Bowen, 1999). It is composed of five dimensions (working with chemicals, using equipment and procedures, collecting data, working with other students, and having adequate time) explored by means of 20 questions in total (4 items per dimension). Thus, it measures several sources of anxiety in chemistry laboratories rather than overall anxiety. This instrument has been validated using

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factor analysis. Interestingly it explores a dimension related to collaborative work that is frequently put in place in analytical chemistry laboratories due to limited access to instruments and to favour pair interactions.

The CLAI questionnaire was recently implemented with additional questions referent to practical work that may affect chemistry laboratory anxiety (i.e. asking for help from a demonstrator, interpreting the data and answering assessed questions) as well as questions relative to chemistry laboratory self-efficacy for each aspect of the laboratory work considered for anxiety, resulting in the CLASEQ questionnaire (Rumme et al., 2019). It was tested in 2017 with 1<sup>st</sup>-year university students enrolled in a chemistry unit at an Australian university at the start and end of semester one, and at the start of semester two: as a trend “students reported lower anxiety about the social aspects of laboratory work than about the practical tasks, and lower anxiety about the practical tasks than the cognitive tasks” (Rumme et al., 2019, p. 91), and the opposite was true for self-efficacy. Hence, students were most anxious about the laboratory aspects that most directly impact their final grades, and completing the work on time was the aspect of laboratory work that students had lowest self-efficacy about. However, since the resulting CLASEQ questionnaire was not thoroughly validated via a factor analysis, we decided not to use it in this work.

Thus, the CLAI questionnaire was retained in our study. It is intended to enable comparison of different instructional approaches used to teach in chemistry laboratories. Our concern to integrate digital resources before or in-between lab sessions may be considered as flip teaching, so that this approach might be assessed with this instrument. In addition, the CLAI questionnaire was used with some minor modifications by several authors in previous studies under undergraduate and graduate contexts quite similar to ours, and interesting data were collected (Kurbanoglu and Akim, 2010). The original CLAI questionnaire in English was also translated in Turkish as well as in Spanish for its use in respectively Turkey (Kurbanoglu and Akim, 2010; Aydogdu, 2017; Alkan, 2021; Alkan and Koyuncu, 2017; Ural, 2016) and Latin America (Avila-Ascanio and Gualdrón-Pinto, 2022).

### Interrelation between these two constructs

Anxiety is generally admitted as a factor that influences self-efficacy, and anxiety has been reported to be negatively associated with self-efficacy, especially in the field of science. For example, it was reported that chemistry laboratory anxiety (addressed using the CLAI questionnaire) was correlated negatively to self-efficacy (addressed using the Motivated Strategies for Learning Questionnaire), and that self-efficacy predicted chemistry laboratory anxiety in a negative way (Kurbanoglu and Akim, 2010); findings were reported for 395 undergraduate chemistry students in Turkey. Similarly, for near 150 first-year students in Australia, an inverse correlation was observed between chemistry laboratory self-efficacy and chemistry laboratory anxiety for each of the same aspect of laboratory work (Spearman's rho correlation values in the range -0.428 to -0.656 with p-values < 0.05) (Rumme et al., 2019). Also, it was reported that high school students “who have anxiety about working with chemicals and tools in chemistry laboratory have low psychomotor self-efficacy beliefs” (Alkan, 2021, p. 35).

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On the other hand, it seems that “self-efficacy does not play a significant role in anxiety” (Trisnaningati, 2021, p. 6727). In the meantime, anxiety and self-efficacy are likely to dynamically interact, so that a “dual intervention” approach, focusing on increasing self-efficacy and decreasing anxiety is recommended (Burns et al., 2021). In this work, we aimed at investigating if the use of the CHIMACTIV resources for the preparation of chemistry lab sessions has a positive impact on these two constructs simultaneously.

### Objective of the study

In this study, we attempted to assess more precisely the impact of consulting targeted open online CHIMACTIV resources as pre-laboratory activities on students' perception of their experimental self-efficacy and anxiety in the context of chemistry laboratory teaching. An additional objective was to confirm the correlation between experimental self-efficacy and chemistry laboratory anxiety, and to explore the interrelations between their dimensions to gain a more nuanced understanding.

Our work was guided by the following research questions:

RQ1 - *Does consulting online resources (with more or less guidance) prior to practical sessions have an impact on students' sense of self-efficacy in successfully completing their practical sessions (experimental self-efficacy)?*

RQ2 - *To what extent these open online resources used for pre-laboratory activities influence students' perception of their anxiety when undertaking practical training in the chemistry laboratory (chemistry laboratory anxiety)?*

RQ3 - *Is there a correlation between these two constructs, and between their respective subscale dimensions?*

## Methods

### Instrument for collecting data

Students' perception was assessed using an anonymous online (Google form) single questionnaire containing three sections with a total of 41 questions.

The first section aimed at collecting information on our students' profiles, including gender, current academic program and previous academic background, as well as their usage (or not) of the CHIMACTIV website (7 questions) (see **Appendix Table A.1**). Students were asked how frequently they consulted the CHIMACTIV website (options: once, 2–5 times, 6–10 times, 11 times or more) and the average time they spent on these resources per consultation (options: <2 min, 2–5 min, 5–15 min, 15–30 min, 30 min–1 h, >1 h) during the program or the teaching activity.

Then the questionnaire was further composed of 32 items in total: 12 questions assessing experimental self-efficacy (modified ESE exploring the four dimensions “conceptual understanding”, “laboratory hazards”, “procedural complexity” and “sufficiency of resources”, with three items per dimension) and 20 questions assessing chemistry laboratory anxiety (modified CLAI exploring the five dimensions “working with chemicals”, “using equipment and procedures”, “collecting data”, “working with other students”, and “having enough time” with four items for each dimension), all rated on a 5-point Likert type scale (choices: totally disagree 1 – 2 – 3 – 4 – 5 totally agree). At the top of the modified ESE section, a definition

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of chemistry laboratory self-efficacy was provided (see **Appendix Table A.2**) to help students better understand the topics addressed. Similarly, for the anxiety section, a definition of chemistry laboratory anxiety was also provided at the beginning of this section (see **Appendix Table A.3**) to clarify the construct being measured.

To avoid assessing the impact of consultation of any available digital resource, we made changes to the initial wording of the questions of the original ESE and CLAI questionnaires, in order to systematically inquire about the perceived positive effect of consulting the CHIMACTIV resources on the item being assessed. Then, to ensure correct understanding by our students, French translation was performed by the co-authors of this article (who are teachers in chemistry) with the aid of the online DeepL website where back translation was systematically included (see **Table A.2** and **Table A.3** in **Appendix**).

### Participants, teaching contexts and administration of the questionnaire

As students' experience in the chemistry laboratory may depend on several factors within and across institutions (such as the collaborative character of the tasks, the variety of the activities, the students' backgrounds as well as interactions with their teachers), we have considered several educational contexts (teacher training college, university, and an engineering school) in order to increase the scope of our results. A total of six cohorts were included in this study (125 students; among them 30 undergraduate and the others graduate). Details of the programs and profiles of the students for each cohort are given in **Table 1**. Interestingly, for three cohorts the students were mainly chemists, for two other cohorts they were mainly biochemists, and for the last cohort they were mainly biologists. We may hypothesise that biologists (and possibly biochemists) would have different attitudes towards analytical chemistry than chemists; if so, possible cohort effects could be anticipated in our results.

During their course, students were oriented by their teacher towards the consultation of specific resources of the CHIMACTIV website in order to prepare the experimental sessions as illustrated in **Figure 2**. Self-consultation of these resources was advisable for the students of all cohorts considered, in order to prepare for lab sessions. From our practice it seems that targeting the resources to be consulted by the students, with their corresponding direct links (URL links), in line with the forthcoming lab sessions is helpful for the students. Then presenting orally the recommendations of consulting the resources with the expected benefits for the students, coupled with detailing these recommendations on a paper or an online page of the learning management system (such as the Moodle course) is fruitful.

The resources to consult varied depending on the educational context, in particularly the initial background of the students as well as the experiments planned during the lab sessions (details are given in **Appendix Table A.4**). In the particular case of cohort 3, students

were asked to complete an online quiz embedded in an H5P activity module within Moodle called 'Interactive Content'. This activity, entitled "How to succeed in your practical sessions on "Chromatography, detection and quantitative analysis"" aimed to prepare students for key steps in their practical sessions; it was published online approximately one month before the lab sessions. This activity was not marked and could even be attempted several times to achieve the highest possible score. Failure to complete this activity did not result in a penalty and did not prevent students from accessing the practical sessions.

The laboratory instruction style varied (structured-inquiry or expository, and guided-inquiry or problem-based) depending on the educational context as detailed in **Table 2**. As in expository instruction lab understanding is mainly developed outside of the lab, thanks to post-lab activities (Domin, 2007), in such teaching scenario for cohort 6 post-lab sessions were scheduled that were dedicated to data treatment and interpretation thanks to targeted bibliography analysis.

At the end of the course, students of the considered cohort received the link towards the online questionnaire containing all the questions and definitions of the constructs concerned (except for cohort 2: the link was sent at the end of the year). The 100% response rate at AgroParisTech could be explained by the mode of administration (the questionnaire was completed in person at the end of a teaching session in the presence of instructors, which ensured immediate participation), as well as the fact that in this institution students are accustomed to feedback practices. No specific incentive structures were implemented in either case.

Filling the questionnaire was optional for the students, and no extra mark was delivered for that. The collected responses were anonymous. Consents were obtained from the students to participate to this study, and the study was conducted in line with ethical guidelines of the three institutions concerned (AgroParisTech, ENS Paris-Saclay and UFR Sciences from the Université Paris-Saclay).

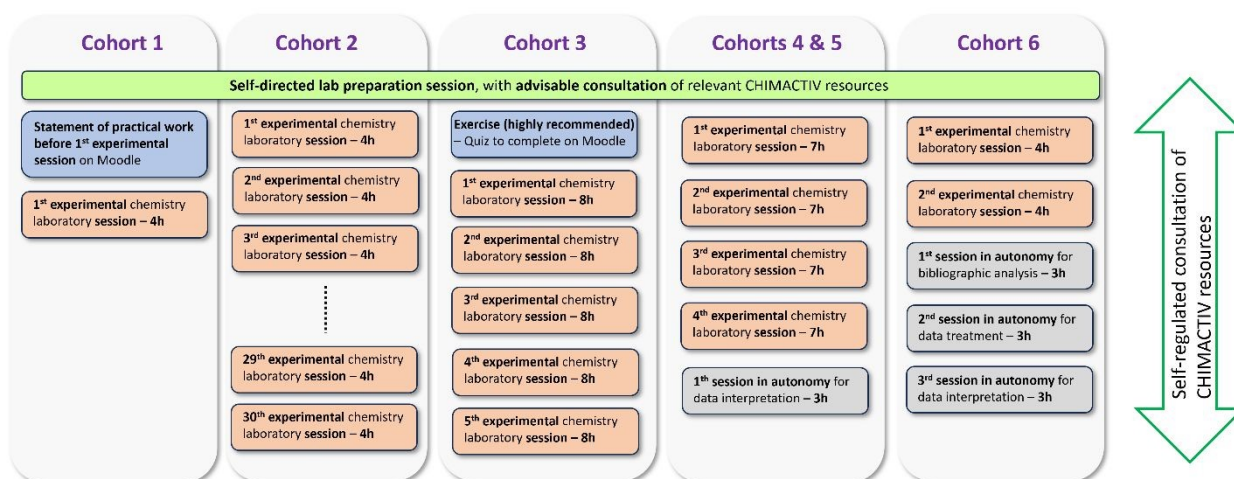
### Data treatment

Once the data had been collected (99 respondents in total), students who claimed they did not use the CHIMACTIV website during the concerned course were removed, since our aim was to assess the impact of using these resources on preparing students for lab sessions, focusing on chemistry lab anxiety and self-efficacy. Students who did not use the resources to prepare for the laboratory sessions argued that they did not need them or had not been informed about them.

Finally, data were retained from 89 respondents. Then two types of treatment were performed. First, data were treated as ordinal to obtain percentage in agreement with each item (calculated using those responding "4" or "5"). Then data were treated as numerical values to facilitate their compilation. In particular, the values were

**Table 1:** details of the cohorts considered in this work (total number of students: 125; total number of respondents: 99; total number of respondents using CHIMACTIV and considered in this work: 89)

Cohort code	Faculty of the Université Paris-Saclay operating the course	Level of the students	Profile of the students	Period of collecting the data	Academic program	Enrolled course	Number of students in the cohort	Rate of respondents to the questionnaire	Rate of CHIMACTIV users among respondents
1	ENS Paris-Saclay (pre-service teacher college)	Undergraduate (third-year of bachelor)	Future scientists (chemists)	June 2023	Chemistry	Analytical chemistry	30	43.3%	88.2%
2		Graduate (second-year of master)	Future teachers (chemists)	June 2024	Teacher training	Preparation of lectures and practical work	14	42.9%	85.7%
3	UFR Sciences (university)	Graduate (first-year of master)	Future scientists (chemists)	March-April 2024	Chemistry	Analytical chemistry	25	80.0%	100.0%
4	AgroParisTech (engineering school)	Graduate (first-year of master)	Future scientists (biochemists)	April 2023	Nutrition and Food Sciences	Experimental workshops	17	100.0%	94.1%
5		Graduate (first-year of master)	Future scientists (biochemists)	May 2024	Nutrition and Food Sciences	Experimental workshops	22	100.0%	83.4%
6		Graduate (second-year of master)	Future engineers (biologists)	October 2023	Chemical risk analysis	Environmental contaminants	17	94.1%	93.8%

**Figure 2:** teaching contexts and scenarios for using the CHIMACTIV resources to prepare experimental sessions in our study – the chemical laboratory sessions are highlighted in orange color, while home work for preparation is indicated in green color. The additional use of Moodle is underlined by the blue color, and post-lab sessions in autonomy scheduled in students' timetable are indicated in grey color. Consultation of the CHIMACTIV website was also possible during the lab sessions and after these sessions.**Table 2:** details relative to the experimental part allocated in each program included in this survey, as well as to the schedule and organization of the experimental sessions (the durations indicated are those scheduled for students in their timetable).

Cohort code	Duration of the teaching unit and period covered	Content of the teaching unit	Total duration allocated to experimental work	Schedule of the sessions for the experimental work	Laboratory instruction style according to Domin (1999)	Laboratory instruction style according to Buck et al. (2008)	Expected production from students	Moment when students were asked to complete the questionnaire
1	5h over 6 weeks	Theoretical lecture, experimental and feedback sessions	4h	1 lab session of 4h	Problem-based	Guided inquiry	Report	End of the teaching unit
2	7 months	Experimental sessions only	120h	30 lab session of 4h	Expository	Structured inquiry	Oral presentation	End of the academic year
3	40h over 2 weeks	Experimental sessions only	40h	5 lab sessions of 8h	Expository	Structured inquiry	Report	End of the teaching unit
4 and 5	80h over 2 weeks	Theoretical lectures, tutorials and experimental sessions	28h	4 lab sessions of 7h + 1 post-lab session of 3h in autonomy (data treatment and interpretation)	Problem-based	Guided inquiry	Report	End of the teaching unit
6	48h over 4 weeks	Theoretical lectures and experimental sessions	17h	2 lab sessions of 4h + 3 post-lab sessions of 3h in autonomy (bibliography analysis, data treatment and interpretation)	Expository	Structured inquiry	Poster	End of the teaching unit

added up for all questions relating to the same dimension before being normalised according to the number of questions. A semi-quantitative analysis was carried out by determining the averages for each of the dimensions of anxiety and self-efficacy.

Cronbach's alpha values were determined to verify the internal consistency of the responses, with satisfactory ranges when gathering the data collected for all students as shown in **Table 3** (overall range 0.85-0.94 and 0.78-0.85, respectively for anxiety and self-efficacy). Considering each cohort separately, all Cronbach' alpha values were acceptable for all dimensions of anxiety. Results were quite satisfactory also when considering data relative to self-efficacy, despite three low values (range 0.50-0.60). However, one value remained clearly unacceptable (below 0.50) for self-efficacy in the case of cohort 1; as a consequence, data collected for this cohort were not retained for exploring this construct here.

Total scores per student for each construct (anxiety or self-efficacy) were also considered. Kolil et al. (2020) analysed the total individual scores collected with their 12-items ESE questionnaire with 5-point Likert type scale upon the following classification: 12 to 23 points (low self-efficacy), 24 to 35 points (below average self-efficacy), 36 to 47 points (above average self-efficacy), 48 to 60 points (high self-efficacy). Results for students from cohorts 2 to 6 are presented in Appendix **Figure A.1**. We adopted the same classification here for data related to self-efficacy, and we adapted this classification to the total individual scores related to the reduction of anxiety based on the 20-items CLAI questionnaire with 5-point Likert type scale as follows: 20 to 39 points (low anxiety reduction), 40 to 59 points (below average anxiety reduction), 60 to 79 points (above average anxiety reduction), 80 to 100 points (high anxiety reduction). Results for students from all cohorts are presented in Appendix **Figure A.2**.

Descriptive statistics and boxplots were obtained using the Excel software. Non-parametric statistical tests were applied, considering the initial ordinal character of our data and the limited number of students in the cohorts. The non-parametric statistical test of Kruskal-Wallis was performed for comparing several sets of data (unpaired data) for each dimension explored in order to investigate for a potential cohort effect. When considering all the data relative to a construct, the non-parametric statistical Friedman test was performed to assess if the consultation of the CHIMACTIV website impacts differently the dimensions of this construct (paired data). In case of rejection of the null hypothesis of the Friedman's test, a Conover's post hoc analysis was performed to investigate statistically significant differences between two dimensions.

Finally, to determine correlations between the dimensions of the two constructs, the Spearman Rho correlation coefficient was calculated. Statistical tests were performed using the corresponding Excel tools from the Anasats website (<https://www.anasats.fr/telechargements/>), with additional confirmation of test results on the BiostatGTV online platform (<https://biostatgv.sentiweb.fr/?module=tests>), except the Conover's post hoc test performed using the JASP software (version 0.95.4).

## Results

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Only students that consulted the CHIMACTIV resources were considered. They represent a major part of our target audience: 83.4 to 100.0% of the respondents depending on the cohort as indicated in **Table 1**. The questionnaire response rate was elevated for future scientists and engineers (cohorts 3-6, ranging from 80.0 to 94.0%) as shown also in **Table 1**. On the other hand, it remained around 43% for students from the teacher training college (cohorts 1-2); this observation was disappointing since we initially expected that future teachers might be enthusiasts for exploring digital resources and providing data to assess their pedagogical benefit for the students. Anyway, we have considered that these response rates were sufficient to use the data collected in our study.

Whatever the construct explored, anxiety or self-efficacy, the questions were all turned positively, so that responses indicating student agreement were in favour of a benefit of using the CHIMACTIV resources.

### Usages of CHIMACTIV resources within our cohorts

When considering all cohorts, the majority (59.6%) of our students who declared using the CHIMACTIV website consulted these resources between 2 to 5 times as illustrated in **Figure 3a**. It is important to point out that near 25% of them used these resources from 6 to 10 times during the considered course, and even 9% declared more 11 times of more. The average time per consultation was primarily (42.7% of our respondents) between 5 and 15 min during our study as shown in **Figure 3b**. Again, extensive consultation of the CHIMACTIV website was noted for some students, with average time per consultation in the range 15 to 30 min for near 25% of our respondents, and even 10% of them who declare to spend 30 min or more (even above 1h) on average for each consultation.

### Students' perception of their experimental self-efficacy after consulting CHIMACTIV resources

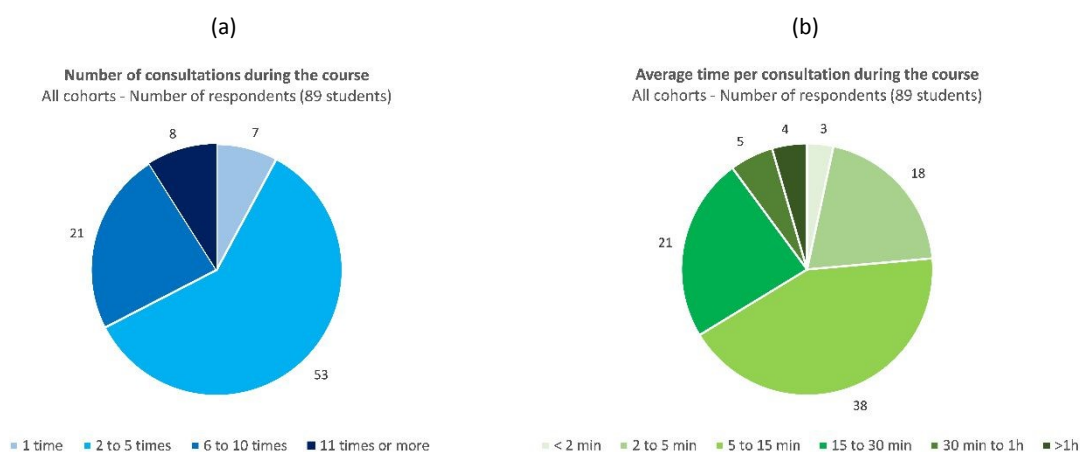
For self-efficacy, the percentage of agreement ranged from 49.3 to 86.8% depending on the questions and considering cohorts 2 to 6 all together as illustrated by **Figure 4**. Values were above 50% for all questions except one (Q5) but the percentage is near 50% for this question. The highest values are observed for the dimension "understanding concepts" (Q1-Q3, with values in the range 76.3 to 86.8%). The second dimension with elevated percentages is "sufficiency of resources" (Q10-Q12, with values ranging from 60.5 to 73.6%). This tendency is observed for each cohort separately, except in the case of cohort 5 with a value of only 47.4% for Q11. Interestingly, for cohort 6 the dimension "procedural complexity" (Q7-Q9) faces values for the percentage of agreement that are very similar to the dimension "sufficiency of resources" (53.3 to 86.7% to be compared to 66.7 to 86.7%); the same tendency is visible for cohort 2 (50.0 to 100% to be compared to 83.3 to 100%).

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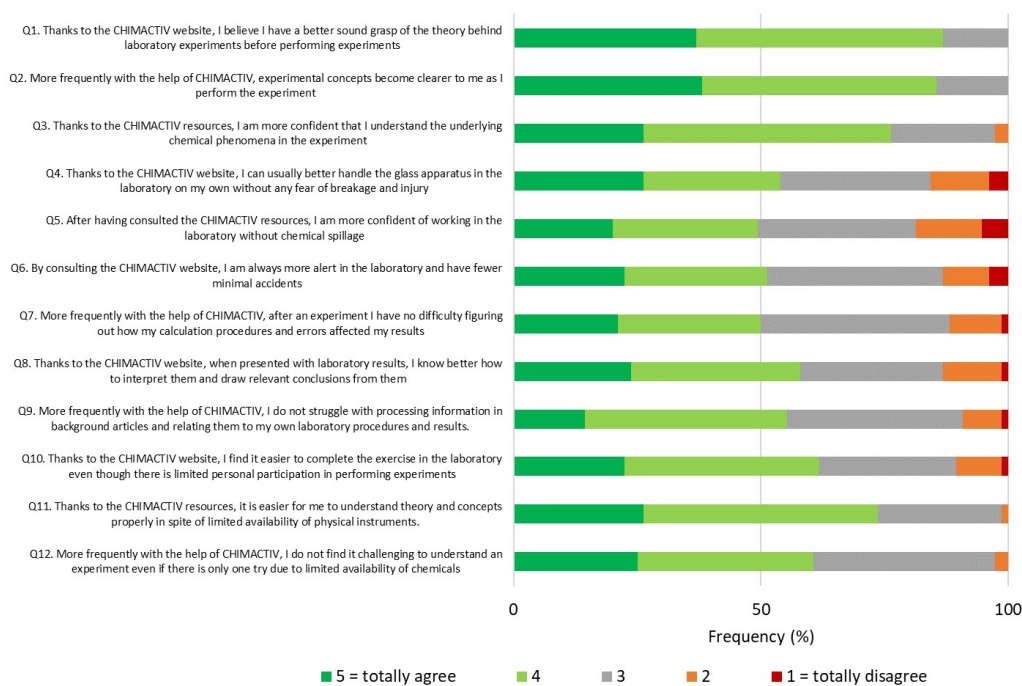
**Table 3:** Values of the Cronbach's alpha (values above 0.60 are considered acceptable, values in the range 0.50-0.60 are low but still acceptable, \*values below 0.50 are considered unacceptable).

Dimension explored	Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5	Cohort 6	All cohorts	Cohorts 2-6
<b>Chemistry laboratory anxiety</b>								
working with chemicals	0.87	0.96	0.91	0.89	0.86	0.90	0.90	
using equipment and procedures	0.82	0.88	0.90	0.88	0.72	0.87	0.85	
collecting data	0.82	0.98	0.94	0.77	0.80	0.87	0.87	
working with other students	0.97	0.97	0.93	0.96	0.96	0.88	0.94	
having adequate time	0.93	0.95	0.96	0.87	0.83	0.94	0.91	
<b>Experimental self-efficacy</b>								
conceptual understanding	0.55	0.83	0.85	0.94	0.92	0.75	0.85	0.87
laboratory hazards	0.68	0.83	0.89	0.94	0.52	0.86	0.83	0.84
procedural complexity	0.32*	0.97	0.86	0.74	0.88	0.67	0.82	0.84
sufficiency of resources	0.57	0.65	0.79	0.87	0.88	0.73	0.78	0.80



**Figure 3:** usages of CHIMACTIV website, considering all cohorts (89 students): (a) number of consultations by the students during the considered course; (b) average time per consultation.

### Experimental self-efficacy - Cohorts 2 to 6



**Figure 4:** percentage of agreement for all questions relative to experimental self-efficacy, considering cohorts 2 to 6 (76 students).

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The benefit of consulting the CHIMACTIV resources on students' perception of their chemistry lab self-efficacy is observed.

The classification of students according to their total individual score reveals that most (92%) of our students perceive an increase of their self-efficacy thanks to the CHIMACTIV resources consultation (high self-efficacy for 37%, and above average self-efficacy for 55% as illustrated in **Figure A.1**). The remaining 8% of students present total scores corresponding to a below average self-efficacy.

Considering cohorts 2 to 6 together, mean scores values ranged from 3.53 to 4.16 depending on the dimension of self-efficacy explored (see **Figure 5**) (mean scores ranged from 3.42 to 4.24 for individual questions as indicated in **Appendix Table A.5**). A Friedman test revealed that the score differences among the dimensions were significant ( $p$ -value  $< 0.001$ ). Pairwise comparison with the Conover test indicated that the "understanding concepts" dimension had a mean score value (4.16) significantly higher than the scores of any other dimension ( $p$ -values  $< 0.001$ ). Also, the "sufficiency of resources" dimension faced a mean score (3.85) higher than the one reported for the "procedural complexity" and "laboratory hazards" dimensions ( $p$ -value 0.008 and 0.006 respectively). For each of self-efficacy dimension considered, the Kruskal-Wallis test revealed no significant effect of the cohort ( $p$ -values in the range 0.094-0.917).

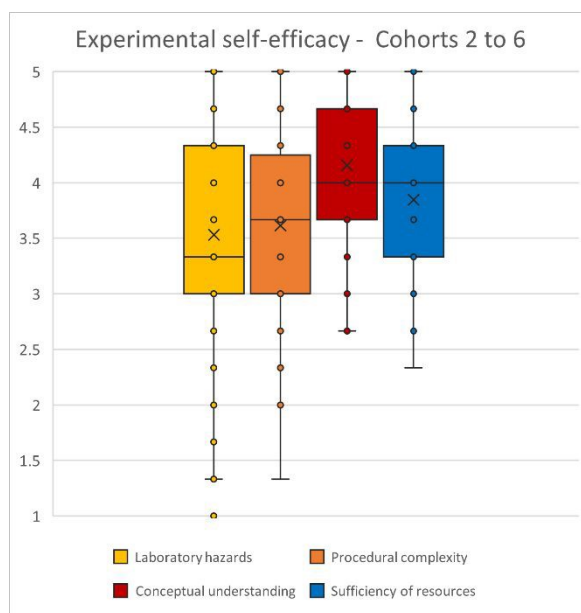
#### Students' perception of their chemistry laboratory anxiety after consulting CHIMACTIV resources

The percentage of agreement with the questions relative to anxiety ranged from 32.6 to 65.4% depending on the questions and considering all cohorts together (see **Figure 6**). Values were above 50.0% for five questions: Q2, Q3, Q7, Q12 and Q17. It is interesting to notice that four of them explore the same dimension that is "using equipment and procedures". Looking in detail of data by cohort, another interesting result can be noticed. For future teachers' students (cohorts 1 and 2), values were also above 50.0% for the four

questions relative to "collecting data" (Q3, Q8, Q13 and Q18), for cohort 6, the same tendency was observed for the anxiety dimension "working with other students" (Q4, Q9, Q14 and Q19). Since our questions were formulated with positive assertions, this clearly indicates the positive impact of consulting the CHIMACTIV resources on students' chemistry lab anxiety.

The classification of students according to their total individual score reveals that a large majority (78%) of our students perceive a reduction of their anxiety thanks to the CHIMACTIV resources consultation (high anxiety reduction for 24%, and above average anxiety reduction for 54% as illustrated in **Figure A.2**). Only 2% of our students present a total score corresponding to a low anxiety reduction.

Considering all cohorts, mean scores values ranged from 3.24 to 3.71 depending on the dimension of anxiety explored as shown in **Figure 7** (mean scores ranged from 3.12 to 3.85 for individual questions as indicated in **Appendix Table A.6**). The Friedman test revealed that score differences among the dimensions were significant ( $p$ -value  $< 0.001$ ). Pairwise comparison with the Conover test showed that the mean score value (3.71) observed for the "using equipment and procedures" dimension was significantly higher than the scores obtained for any other dimension ( $p$ -values in the range  $< 0.001$  to 0.031). The score attributed to the "collecting data" dimension was lower (3.54), but still significantly higher than the scores of the dimensions "working with chemicals", "working with other students" and "having adequate time" (Conover,  $p$ -values in the range  $< 0.001$  to 0.009 depending on the other dimension considered). For each of the anxiety dimension considered, the Kruskal-Wallis test revealed no cohort effect ( $p$ -values in the range 0.135-0.844), so that mean scores were similar among our cohorts.



**Figure 5:** boxplots of the scores obtained for the four dimensions of experimental self-efficacy considering cohorts 2 to 6 (76 students)

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## Chemistry laboratory anxiety - All cohorts

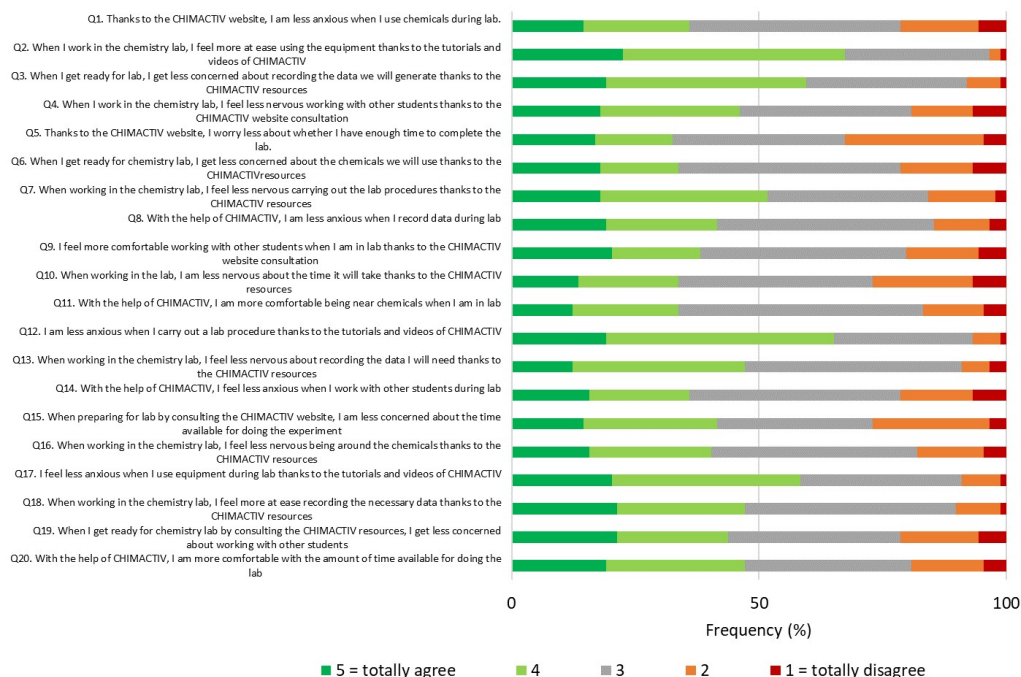


Figure 6: percentage of agreement for all questions relative to chemistry laboratory anxiety, considering all cohorts (89 students).

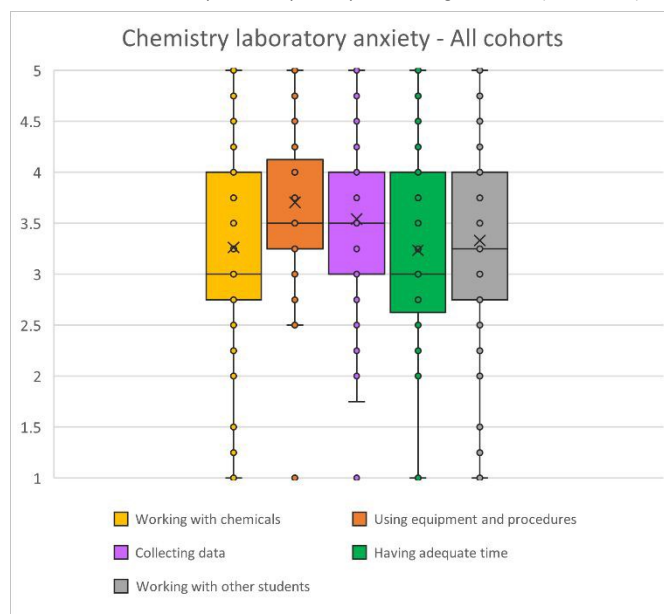


Figure 7: boxplots of the scores obtained for the five dimensions of chemistry laboratory anxiety considering all cohorts (89 students).

### Correlation between experimental self-efficacy and chemistry laboratory anxiety

A positive and significant correlation was observed between the reduction of anxiety and the increase of self-efficacy as indicated by the correlation coefficients shown in **Appendix Table A.7**. Values for these coefficients ranged from 0.40 to 0.67 ( $p$ -values in the range  $2.3 \times 10^{-11}$ –0.0004). Overall, 55% of the coefficients are above the value of 0.50, indicating a strong correlation between the dimensions

concerned. The highest value was observed between the two dimensions "using equipment and procedures" (anxiety) and "sufficiency of resources" (self-efficacy), followed by a similar value (0.65) between the two dimensions "working with chemicals" (anxiety) and "laboratory hazards" (self-efficacy). Interestingly, all the five dimensions of anxiety are strongly correlated to the dimension "sufficiency of resources" of self-efficacy (values above 0.51). Also, the dimension "laboratory hazards" (self-efficacy) was strongly correlated to three dimensions of anxiety, namely "working

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with chemicals”, “working with other students” and “using equipment and procedures” (values above 0.52). Two other strong correlations were observed: between “conceptual understanding” (self-efficacy) and “using equipment and procedures” (anxiety), as well as between “procedural complexity” (self-efficacy) and “working with other students” (anxiety) (values above 0.53). Several subscale correlations are graphically presented in **Figure A.3** of the Appendix.

## Discussion

### Usages of the CHIMACTIV website before lab sessions

One major result of our study is the elevated rate of using CHIMACTIV resources among our respondents. From our experience, this may be strongly related to the teacher attitude to invite students to consult specific resources, and also partly dependent on the reuse of the knowledge explored on the website in class or in lab sessions. In case of cohort 3, students were strongly invited by the teacher to answer an online quiz (available on the learning management system of the university) before the lab session, where answers may be found in the CHIMACTIV website; students had no obligation to access the CHIMACTIV website to answer the quiz, but it was highly recommended by the teacher who provided the direct link to facilitate access to the topic related to the quiz. Students who did not complete this activity were reminded by the lecturer before the practical sessions to encourage them to carry out this preparatory work. This teaching strategy resulted in 100% of the students who have consulted the website.

By combining the preferred number of consultations (2 to 5 times for 59.6% of our students) with the preferred time per consultation (5 to 15 min for 42.7% of our students) reported by our students, the more frequent preparation time with the CHIMACTIV website in this study was in the range 10 to 75 min, that is quite similar to the time reported in a previous study where students had to complete prelab e-quizzes and were encouraged to view instructional videos before analytical chemistry practical classes (i.e. time ranged mostly within 15 and 60 min or more, with 29.2% of students reporting to spend 60 min or more) (Jolley et al., 2016). Looking in detail into the data, it appears that only students from cohorts 3 and 6 reported a consultation time above 60 min (this concerns a total of four students, two from each cohort). This is in line with the on-line quiz completion required for entering the lab session for cohort 3, that encourages the students to consult the CHIMACTIV website to find the correct answers.

### Benefits of the CHIMACTIV website consultation on students' experimental self-efficacy

Mean score values per dimension as well as individual total score values related to self-efficacy are rather high in our study. By comparison, a mean score value of 3.4 has been recently reported for chemical laboratory self-efficacy using a scale composed of 15 items in 5-point Likert type (Sailaubay et al., 2024). Also, even if we cannot directly compare our results with those reported by Kolil et al. (2020) since they performed pre- and post-tests, our scores exceeding the average self-efficacy are higher than the values their reported for their pre-test.

Thus, our results are clearly in favour of a benefit on students' chemistry laboratory self-efficacy belief of consulting the CHIMACTIV resources to prepare the lab sessions. The greatest benefit relates to the “understanding concepts” dimension; this could be explained by the theoretical content provided by the CHIMACTIV website, which enables students to better get the meaning of concepts. This is in line with previous results of Saleh (2009) reporting that students who consulted visualization resources related to experiments before chemical lab sessions improved their understanding of concept and experimental procedures as compared to students who did not.

### Benefits of the CHIMACTIV website consultation on students' chemistry laboratory anxiety

With regard to chemistry laboratory anxiety reduction, the positive effect of consulting the CHIMACTIV resources was observed whatever the dimensions considered (mean scores values above 3.20). It was the most pronounced for the dimension “using equipment and procedures” (mean score 3.71, standard deviation 0.76). This result was predictable, as several of the resources to which students were directed contain experimental details and short videos describing how to use laboratory equipment.

A significant positive effect was also observed for the dimension “collecting data” (mean score 3.54, standard deviation 0.81). We formulate the hypothesis that since students feel more prepared to the lab sessions due to a better understanding of the procedures and how to use the equipment thanks to their consultation of the CHIMACTIV website, there are less anxious for collecting the data during the lab sessions. In addition, due to the responsive digital character of the CHIMACTIV resources, their consultation during the lab sessions is possible, and this could also lead to a reduction of students' anxiety. Indeed, Damo et al. (2020) gave evidence (using the LAQ questionnaire with pre- and post-test) that the integration of mobile applications and videos during lab sessions significantly decreased students' chemistry lab anxiety.

It is noteworthy that our results were similar whatever the cohorts, so that the students' perceptions were comparable for chemists, biochemists and biologists. This was unexpected as previously mentioned. Hence, as we hypothesised that biologists (and possibly biochemists) may have more negative attitudes towards analytical chemistry than chemists, with subsequent higher chemistry anxiety for biologists (and possibly biochemists) than chemists since negative chemistry attitudes were reported to create chemistry anxiety (Kurbanoglu and Akin, 2012), we expected biologists (and possibly biochemists) to face a higher chemistry laboratory anxiety than chemists. Nevertheless, since we measured students' perception of anxiety reduction, possibly they experienced the same perception but we cannot exclude the fact that, on the whole, biologists (and possibly biochemists) faced a higher chemistry laboratory anxiety than chemists. At least this clearly suggests the broad scope of applications of the CHIMACTIV resources in chemistry laboratory teaching programmes.

### Correlation between experimental self-efficacy and chemistry laboratory anxiety

The correlation coefficients assessed in our study between dimensions of chemistry laboratory anxiety and experimental self-

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efficacy are in the same range than those previously reported by Rummer et al. (2019). In our case, values are all positive since we formulated all the questions relative to anxiety as a positive effect of the CHIMACTIV resources, so that we measured a reduction of perceived anxiety instead of assessing the perceived anxiety. Our results do confirm that an increase in experimental self-efficacy is related to a decrease in chemistry laboratory anxiety.

Significant correlations were observed across all dimensions, with 55% of correlations exceeding 0.50, indicating consistently strong relationships between specific aspects of anxiety and corresponding self-efficacy dimensions. These patterns broadly align with Kolil et al. (2020), who reported that all dimensions of self-efficacy contribute to student anxiety in laboratory tasks. Interestingly, the strongest link in our study involved “using equipment and procedures” (anxiety) and “sufficiency of resources” (self-efficacy), providing additional insight compared to Kolil et al. who identified “conceptual understanding” as the most impactful dimension. Notably, all five dimensions of anxiety were strongly correlated with the “sufficiency of resources” dimension of self-efficacy (values above 0.51), which was the least impactful in Kolil’s study. This difference may reflect the context of our study, which involved near a hundred of undergraduate students versus Kolil’s much larger cohort (over 1,000 participants).

### Implications

It is now well-established that academic self-efficacy is a good predictor of academic achievement and performance (Artino, 2012). We may hypothesize that this is similar in the context of chemical laboratory. During experimental sessions, students’ self-efficacy belief will influence their motivation, engagement and performance in the tasks. Indeed, recent results showed a positive and significant relationship between the academic achievement of students in a chemical technology course and their laboratory self-efficacy (Salaubay et al., 2024).

Our results suggest that teachers may consider integrating digital pre-laboratory resources (such as CHIMACTIV in the field of analytical chemistry) into course design, particularly for students with limited prior experience in chemistry. These resources may help structure students’ preparation before laboratory sessions, especially in contexts where anxiety and low self-efficacy are common among less experienced learners. Given that first-year university students are often reported to experience high levels of chemistry anxiety (chemophobia) due to limited prior experience (Eddy, 2020), such resources may be particularly relevant at the beginning of university curricula. Teachers can guide students toward specific CHIMACTIV modules depending on pedagogical objectives, such as reinforcing prior knowledge, introducing new scientific concepts, or supporting data analysis skills. The interactive and adaptive nature of these resources makes them suitable for both practical and theoretical learning contexts. In addition, their possible consultation on any digital support favors their use during the experimental sessions, so that students may complement their pre-laboratory work during these sessions.

## Submitted to Chemistry Education Research and Practice

### Limitations

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While the overall number of participants was adequate, some cohorts included relatively few students, and participation rates varied across groups. These factors may limit the generalizability of the findings and suggest that results should be interpreted with caution. In addition, data were collected by the teachers themselves, at the end of the considered courses, who were also the designers and creators of the CHIMACTIV resources. Consequently, our data may be affected by a desirability bias, although the responses to the questionnaire remained anonymous. Our results should be confirmed on larger cohorts, and possibly in other educational contexts, especially by considering first-year and second-year undergraduate students since they were absent from our cohorts.

Considering our instrument, we used a Likert type scale presented as a numerical rating scale, with 1 indicating “totally disagree” and 5 indicating “totally agree”. For the ESE questionnaire as well as the CLAI questionnaire, Kolil et al. (2023) and Bowen (1999), respectively, preferred to use the indications of “strongly” instead of “totally”. We are aware of the fact that this minor difference may have influenced the students’ answers, and possibly this may explain the elevated percentage of neutral (value of 3) answers in our data (mean value of 38% for anxiety with a range covering 20 to 60%; values are lower for self-efficacy, with a mean value of 28% and a range covering 13 to 38%). In addition, we cannot exclude the fact that some students chose the neutral option since they believed their true response was not desirable.

In addition, the two revised questionnaires we used in this study should have been tested, especially since the initial versions were validated in English version when we used a translated French version, and also since we made changes to the initial wording of the questions. It would have been more rigorous to validate they are still aligned with the anxiety and self-efficacy models considered, by performing a confirmatory factorial analysis.

Also, our instrument provided data on anxiety related to the chemistry laboratory, without distinguishing between the different types of anxiety. It would be particularly interesting to gather further information in order to distinguish between “achievement anxiety” (related to performance, success or failure) and “epistemic anxiety” (related to knowledge and the generation of knowledge); this would help teachers to better support their students by helping them to manage and alleviate their anxiety. These two types of anxiety have recently been clarified in the context of the analytical chemistry laboratory: “achievement anxiety” (or “performance anxiety”) is experienced “when students are afraid of not being able to operate certain instruments, making procedural mistakes, and not being able to finish on time”, whereas “epistemic anxiety” arises “when students experience the discomfort of not knowing why something went wrong in the experiment” (Agustian et al., 2025, p. 732). The “Epistemically Related Emotion Scales” instrument could be used (Perkrun et al., 2017), especially in its short version, to track the dynamics of “epistemic anxiety” (as well as other epistemic emotions) among students in the chemistry laboratory.

Finally, we have regarded anxiety here as a negative emotion that hinders learning. Previous findings have shown that its role is more ambiguous. “Achievement anxiety” can sometimes be beneficial for learning (for example by inducing motivation to work harder)

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(Perkrun and Stephens, 2012). On the other hand, “epistemic anxiety” may play a role in guiding cognitive processes and driving scientific inquiry (Agustian et al., 2025).

## Conclusions

Our results show that when learners consult targeted resources (selected by the teacher) on the CHIMACTIV website before the experimental sessions, they perceive an increase of their self-efficacy and a reduction of their anxiety in the chemistry laboratory. This is aligned with the observations made by our teachers during the sessions, who note that students who have visited the site behave in a more proactive and thoughtful manner than students from previous cohorts who did not have access to these digital educational resources.

All of this suggests that consulting the CHIMACTIV site has a beneficial effect on chemistry learning. The originality of our study lies in the fact that we have considered different higher education contexts (teacher training college, university, and an engineering school), covering several academic levels, students’ profiles, as well as laboratory instruction styles. Our results also confirm the strong correlation between experimental self-efficacy and chemistry laboratory anxiety.

These findings and the observed correlations would benefit from replication in other contexts or with larger sample sizes, particularly given the differences observed compared to Kolil et al. (2020). A mixed-methods study incorporating interviews could also provide a deeper understanding of the mechanisms underlying these effects.

## Author contributions

All authors contributed to data collection, writing – review and editing, as well as funding acquisition. Valérie Camel’s additional contribution was conceptualization, data curation, formal analysis methodology, validation, visualization, writing – original draft. Jonathan Piard’s additional contribution was conceptualization, data curation and formal analysis methodology.

## Conflicts of interest

There are no conflicts to declare. The authors will have no financial nor professional benefit related to the external use of the CHIMACTIV website. The same applies to the institutions to which they belong.

## Data availability

The data supporting this article have been included as part of the Supplementary Information. In addition, raw data may be deposited on an open access repository if this is of interest to the teaching or scientific community.

## Ethical considerations

Informed consents were obtained from the students to participate to this study, and filling the questionnaire was optional for them. As

this step occurred at the end of the teaching unit, this did not influence the consultation of the CHIMACTIV resources before the laboratory sessions nor the behaviour of students during these sessions.

The researchers were also the teachers, but they did not deliver any extra mark for filling the questionnaire and participating to the study, and students who did not respond were not penalized. As a matter of fact, since all the collected responses were anonymous using an online questionnaire, the researchers had no information about the persons responding. Students’ profile data were collected to give indication about previous scientific knowledge of the respondents, but at the end these data remained untreated. Hence, individual’s privacy and confidentiality have been protected.

The study was conducted in line with ethical guidelines of the three institutions concerned (AgroParisTech, ENS Paris-Saclay and UFR Sciences from the Université Paris-Saclay).

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## References

- Acar Sesen A. and Mutlu A. (2014), An action research to overcome undergraduates’ laboratory anxiety. *Procedia – Social and Behavioral Sciences*, **152**, 546-550.
- Achuthan K. and Murali S.S. (2015), A comparative study of educational laboratories from cost & learning effectiveness perspective. In *Advances in Intelligent Systems and Computing*, 349, p. 143-153. Silhavy R. et al. (eds.), *Software Engineering in Intelligent Systems*, Springer International Publishing Switzerland.
- Agustian H.Y. and Seery M.K. (2017), Reasserting the role of pre-laboratory activities in chemistry education: a proposed framework for their design. *Chemistry Education Research and Practice*, **18**, 518-532.
- Agustian H.Y., Finne L.T., Jørgensen J.T., Pedersen M.I., Christiansen F.V., Gammelgaard B. and Nielsen J.A. (2022), Learning Outcomes of University Chemistry Teaching in Laboratories: A Systematic Review of Empirical Literature. *Review of Education*, **10**(2), 1-41.
- Agustian H.Y. (2025), Recent advances in laboratory education research. *Chemistry Teacher International*, **7**(2), 217–224.
- Agustian H.Y., Gammelgaard B., Rangkuti M.A. and Niemann J. (2025), “I feel like a real chemist right now”: epistemic affect as a fundamental driver of inquiry in the chemistry laboratory. *Science Education*, **109**, 722-744.
- Alkan F. (2016), Development of chemistry laboratory self-efficacy beliefs scale. *Journal of Baltic Science Education*, **15**(3), 350-359.
- Alkan F. and Koyuncu N. (2017), Analyzing the relationship between chemistry motivation with chemistry laboratory anxiety through

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- structural equation modeling. *The Eurasia Proceedings of Sciences, Technology, Engineering & Mathematics (EPSTEM)*, **1**, 83-89.
- Alkan F. (2021), Examining the high school students' chemistry motivation, chemistry laboratory anxiety and chemistry laboratory self-efficacy beliefs towards different variables. *Journal of Educators, Teachers and Trainers*, **12**(3), 30-40.
- American Chemical Society (undated). Guidance for developing & teaching analytical chemistry. <https://www.acs.org/content/dam/acsorg/education/standards-guidelines/approval-program/resources/analytical-guidance-2025.pdf> (consulted on line on 30 March 2026).
- Artino A.R.Jr. (2012) Academic self-efficacy: from educational theory to instructional practice. *Perspectives on Medical Education*, **1**, 76-85.
- Avila-Ascanio L.F. and Gualdron-Pinto E. (2022), Chemistry Laboratory Anxiety in Eighth-grade Students from Barrancabermeja, Colombia. *Acta Scientiae*, **24**(6), 462-489.
- Aydogdu C. (2017), The effect of chemistry laboratory activities on students' chemistry perception and laboratory anxiety levels. *International Journal of Progressive Education*, **13**(2), 85-84.
- Bandura A. (1977) Self-efficacy: toward a unifying theory of behavioral change. *Psychological Review*, **84**(2), 191-215.
- Bergquist J., Emmer A, Farbrot A. and Turner C. (2023), Research and education in analytical chemistry – industrial and academic perspectives from a survey conducted in Sweden. *Analytical and Bioanalytical Chemistry*, **415**, 2151-2161.
- Boesdorfer S.B. and Livermore R.A. (2018), Secondary school chemistry teacher's current use of laboratory activities and the impact of expense on their laboratory choices. *Chemistry Education Research and Practice*, **19**, 135-148.
- Bortnik B., Stozhko N., Pervukhina I., Tchernysheva A. and Belysheva G. (2017), Effect of virtual analytical chemistry laboratory on enhancing student research skills and practices. *Research in Learning Technology*, **25**, 1-20.
- Bouffard-Bouchard T. and Pinard A. (1988) Sentiment d'auto-efficacité et exercice des processus d'auto-régulation chez des étudiants de niveau collégial. *International Journal of Psychology*, **23**, 409-431.
- Bowen C.W. (1999), Development and score validation of a chemistry laboratory anxiety instrument (CLAI) for college chemistry students. *Educational and Psychological Measurement*, **59**(1), 171-185.
- Bretz S.L. (2019), Evidence for the importance of laboratory courses. *Journal of Chemical Education*, **96**, 193-195.
- Brooks M. and Lawal W. (2025), The development of standards & guidelines for undergraduate chemistry education. *Chemistry Teacher International*, **7**(2), 377-384.
- Bruck L.B. and Towns M.H. (2009), Preparing students to benefit from inquiry-based activities in the chemistry laboratory: guidelines and suggestions. *Journal of Chemical Education*, **86**(7), 820-822.
- Buck L.B., Bretz S.L. and Towns M.H. (2008), Characterizing the level of inquiry in the undergraduate laboratory. *Journal of College Science Teaching*, **September/October**, 52-58.
- Burns C.E., Martin A.J., Kennett R.K., Pearson J. and Munro-Smith V. (2021), Optimizing science self-efficacy: a multilevel examination of the moderating effects of anxiety on the relationship between self-efficacy and achievement in science. *Contemporary Educational Psychology*, **64**, 101937.
- Camel V., Maillard M.-N., Descharles N., Le Roux E., Cladière M. and Billault I. (2021), Open digital educational resources for self-training chemistry lab safety rules. *Journal of Chemical Education*, **98**(1), 208-217.
- Camel V., Maillard M.-N., Piard J., Dumas C., Cladière M., Fitoussi G., Brun E., Billault I. and Sicard-Roselli C. (2020), CHIMACTIV: an open-access website for student-centered learning in analytical chemistry. *Journal of Chemical Education*, **97**(8), 2319-2326.
- Chalupa R. and Nesmerak K. (2023), Chemophobia and practical chemistry: the laboratory as a place of origin of, on the contrary, suppression of the fear of chemistry? *Monatshefte für Chemie - Chemical Monthly*, **154**, 957-965.
- Cook M.P. (2006), Visual representations in science education: the influence of prior knowledge and cognitive load theory on instructional design principles. *Science Education*, **90**(6), 1073-1091.
- Dalgarno B., Bishop A.G., Bedgood D.R.Jr. and Adlong W. (2012), What factors contribute to students' confidence in chemistry laboratory sessions and does preparation in a virtual laboratory help? *Proceedings of Scholarly Inquiry into Science Teaching and Learning Symposium*, pp. 15-21.
- Damo K.L., Garcia R.T. and Prudente M.S. (2020), Overcoming laboratory anxiety through technology-integrated laboratory activities. *Proceedings of the IC4E 2020 congress, January 10-12, 2020, Osaka, Japan*, pp. 98-102.
- Danthonny S. (2020), Identifier, mesurer et comprendre les différentes dimensions de l'anxiété d'évaluation des élèves en Education Physique et Sportive. Thèse de Doctorat. Université Aix-Marseille.
- Domin D.S. (1999), A review of laboratory instruction styles. *Journal of Chemical Education*, **76**(4), 543-547.
- Domin D.S. (2007), Students' perceptions of when conceptual development occurs during laboratory instruction. *Chemistry Education Research and Practice*, **8**(2), 140-152.
- Eddy R.M. (2000), Chemophobia in the college classroom: extent, sources, and student characteristics. *Journal of Chemical Education*, **77**(4), 514-517.
- Gist M.E. and Mitchell T.R. (1992), Self-efficacy: a theoretical analysis of its determinants and malleability. *Academic Management Review*, **17**(2), 183-211.
- Gungor A., Kool D., Lee M., Avraamidou L., Eisink N., Albada B., van der Kolk K., Tromp M. and Bitter J.H. (2022), The use of virtual reality in a chemistry lab and its impact on students' self-efficacy, interest, self-concept and laboratory anxiety. *Eurasia Journal of Mathematics, Sciences and Technology Education*, **18**(3):em2090.
- Hellemans C. (2004), Stress, anxiété et processus d'ajustement face à un examen de statistique à venir. *L'orientation scolaire et professionnelle*, **33**, 1-26.
- Hofstein A. (2004), The laboratory in chemistry education: thirty years of experience with developments, implementation, and research. *Chemistry Education Research and Practice*, **5**, 247-264.
- Hofstein A. and Lunetta V.N. (2004), The laboratory in science education: foundations for the twenty-first century. *Science Education*, **88**(1), 28-54.
- Hofstein A. and Mamluk-Naaman R. (2007), The laboratory in science education: the state of the art. *Chemistry Education Research and Practice*, **8**(2), 105-107.
- Jolley D.F., Wilson S.R., Kelso C., O'Brien G. and Mason C.E. (2016), Analytical thinking, analytical action: using prelab video demonstrations and e-quizzes to improve preparedness for analytical chemistry practical classes. *Journal of Chemical Education*, **93**, 1855-1862.
- Kennepohl D. (2021), Laboratory activities to support online chemistry courses: a literature review. *Canadian Journal of Chemistry*, **99**(11), 851-859.
- Kolil V.K., Muthupalami S. and Achuthan K. (2020), Virtual experimental platforms in chemistry laboratory education and its impact on experimental self-efficacy. *International Journal of Education Technology in Higher Education*, **17**:30
- Kolil V.K., Parvathy S.U. and Achuthan K. (2023), Confirmatory and validation studies on experimental self-efficacy scale with applications to multiple scientific disciplines. *Frontiers in Psychology*, **14**, 1154310.



## Journal Name ARTICLE

- Kovarik M.L. (2025), The undergraduate analytical chemistry curriculum: how we decide what to teach? *Analytical and Bioanalytical Chemistry*, **418**, 9-14.
- Kurbanoglu N.I. and Akim A. (2010), The relationships between university students' chemistry laboratory anxiety, attitudes, and self-efficacy beliefs. *Australian Journal of Teacher Education*, **35**(8), 48-59.
- Kurbanoglu N. I. and Akim A. (2012), The relationships between university students' organic chemistry anxiety, chemistry attitudes, and self-efficacy: a structural equation model. *Journal of Baltic Science Education*, **11**(4), 347-356.
- Loughlin W.A. and Cresswell S.L. (2021), Integration of interactive laboratory videos into teaching upper-undergraduate chemical laboratory techniques. *Journal of Chemical Education*, **98**, 2870-2880.
- Madybekova G., Zabynekova T., Shertayeva N. and Bitursyn S. (2026), Enhancing analytical chemistry education through project-based learning: an empirical study on university students' research and practical skill development. *Chemistry Teacher International*, **January 13**, 1-21.
- Masania J., Grootveld M. and Wilson P.B. (2018), Teaching analytical chemistry to pharmacy students: a combined, iterative approach. *Journal of Chemical Education*, **95**(1), 47-54.
- Matakaa L.M. and Kowalske M.G. (2015), The influence of PBL on students' self-efficacy beliefs in chemistry. *Chemistry Education Research and Practice*, **16**, 929-938.
- Pekrun R. and Stephens E.J. (2012), Academic emotions. In K.R. Harris, S. Graham and T. Urdan. (editors-in-chief), *APA educational psychology handbook, Volume 2: Individual differences and cultural and contextual factors*. Washington, American Psychological Association, p. 3-31.
- Pekrun R., Vogl E., Muis K.R. and Sinatra G.M. (2017), Measuring emotions during epistemic activities: the Epistemically-Related Emotion Scales. *Cognition and Emotion*, **31**(6), 1268-1276.
- Reid N. and Shah I. (2007), The role of laboratory work in university chemistry. *Chemistry Education Research and Practice*, **8**(2), 172-185.
- Rumme C., Clemons T.D. and Spagnoli D. (2019), The impact of several demographic factors on chemistry laboratory anxiety and self-efficacy in students' first year of university. *Student Success*, **10**(1), 87-98.
- Sailaubay A., Myrzakhmetova N., Tunçel M. and Kishibayev K. (2024) Analysis of the relationships between university students' laboratory self-efficacy beliefs, sciences process skills and achievement in chemistry courses. *Journal of Curriculum Studies Research*, **6**(2), 36-51.
- Saleh T.A. (2009), Visualization resources: to better utilize lab-time and to enhance teaching introductory chemistry laboratory. *Journal of Computer Chemistry Japan*, **8**(2), 93-96.
- Sarmouk C., Ingram M.J., Read C., Curdy M.E., Spall E., Farlow A., Kristova P., Quadir A., Maatta S., Stephens J., Smith C., Baker C. and Patel B.A. (2019), Pre-laboratory online learning resource improves preparedness and performance in pharmaceutical sciences practical classes. *Innovations in Education and Teaching International*, **57**(4), 460-471.
- Schmidt-McCormack J. A., Muniz M.N., Keuter E.C., Shaw S.K. and Cole R.S. (2017), Design and implementation of instructional videos for upper-division undergraduate laboratory courses. *Chemistry Education Research and Practice*, **18**, 749-762.
- Seery M.K. (2020), Establishing the laboratory as the place to learn how to do chemistry. *Journal of Chemical Education*, **97**(6), 1511-1514.
- Sharpe P.C. (2012), Who's afraid of the chemistry lab? *Proceedings of the Australian Conference on Science and Mathematics Education*. University of Sydney, Sept. 26<sup>th</sup> to Sept. 28<sup>th</sup>, page 32, ISBN Number 978-0-9871834-1-5.
- Soulé J., Jordheim M., Seland J.G., Grung B. and Myklebust R.A. (2025) Facilitating student preparation and learning in chemistry courses with a virtual laboratory guide. *Nordic Journal of STEM Education*, **9**(2), 348-352. DOI: 10.1039/D6RP00091F
- Stone S. and Arenas B.E. (2025), Characterising the nature and effect of sensory overload in an undergraduate chemistry teaching laboratory. *Chemistry Education Research and Practice*, **article online**.
- Teo T.W., Tan K.C.D., Yan Y.K., Teo Y.C. and Yeo L.W. (2014), How flip teaching supports undergraduate chemistry laboratory learning. *Chemistry Education Research and Practice*, **15**, 550-567.
- Trisnaningati Z.R. (2021), Meta-analysis of self-efficacy and anxiety correlation. *Budapest International Research and Critics Institute-Journal (BIRCI-Journal)*, **4**(3), 6727-6732.
- Ural E. (2016), The effect of guided-inquiry laboratory experiments on science education students' chemistry laboratory attitudes, anxiety and achievement. *Journal of Education and Training Studies*, **4**(4), 217-227.
- Valcárcel, M. (2016) Quo vadis, analytical chemistry? *Analytical and Bioanalytical Chemistry*, **408**, 13-21.
- Veiga N., Luzardo F., Irving K., Rodriguez-Ayan M.N. and Torres J. (2019), Online pre-laboratory tools for first-year undergraduate chemistry course in Uruguay: student preferences and implications on student performance. *Chemistry Education Research and Practice*, **20**, 229-245.
- Washbourn G. (2024), Anxiety and sensory overload: a perspective on how chemistry undergraduate students perceive their time in the lab. *Developing Academic Practice*, July, 41-45.



# Appendix

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**Table A.1:** details of the first section of our questionnaire, addressing the profile of our respondents and their usage of the CHIMACTIV website.

<b>General introduction of the questionnaire</b>		
<p>The teaching team behind the CHIMACTIV website wishes to collect factual data on the site's usefulness for learning, in order to promote its use by other teachers and students. The results obtained from your (anonymous) responses to this questionnaire may be presented at a conference or published in a scientific article. Thank you in advance for the time you take to complete this questionnaire.</p> <p>The questionnaire is composed of two sub-questionnaires: one on the perception of self-efficacy (12 questions) and the other on the perception of anxiety (20 questions). It was developed based on validated questionnaires published in the chemistry education literature. Several questions address the same topic from different angles, which strengthens the reliability of the questionnaire.</p>		
<b>French translation of the general introduction of the questionnaire</b>		
<p>L'équipe enseignante conceptrice du site CHIMACTIV souhaite disposer de données factuelles quant à l'intérêt du site pour les apprentissages, afin de favoriser son utilisation par d'autres enseignant-es et étudiant-es. Les résultats obtenus grâce aux réponses (anonymes) à ce questionnaire pourront faire l'objet d'une communication dans un colloque ou d'un article scientifique. Merci d'avance pour le temps que vous consacrerez à remplir ce questionnaire.</p> <p>Il est composé 2 sous-questionnaires : un sur la perception du sentiment d'auto-efficacité (12 questions) et l'autre sur la perception de l'anxiété (20 questions). Il a été établi sur la base de questionnaires validés et publiés dans la littérature relative à l'enseignement de la chimie. Plusieurs questions traitent d'un même sujet avec différentes nuances, c'est ce qui fait la robustesse du questionnaire.</p>		
<b>Student's profile</b>	<b>Items with options for the answers</b>	<b>French translations of the items with options for the answers</b>
	<b>Gender:</b> male / female / non-binary	<b>Vous êtes :</b> un homme/ une femme / non binaire
	<b>Your current academic level during this school year (Year N)</b> (for engineering curriculum: 1A = L3, 2A = M1, 3A = M2): L1 / L2 / L3 / M1 / M2	<b>Votre niveau d'étude durant l'année scolaire en cours (année N)</b> (pour cursus ingénieur : 1A = L3, 2A = M1, 3A = M2) : L1 / L2 / L3 / M1 / M2
	<b>Your previous academic background:</b> <ul style="list-style-type: none"> <li><b>Year N-1:</b> Level – High School, CPGE, L1, L2, L3, M1, M2, IUT, BTS, Other Main discipline: Biology / Chemistry / Physics / Physics-Chemistry / Chemistry-Biology / Other (please specify)</li> <li><b>Year N-2:</b> Level – High School, CPGE, L1, L2, L3, M1, M2, IUT, BTS, Other Main discipline: Biology / Chemistry / Physics / Physics-Chemistry / Chemistry-Biology / Other (please specify)</li> </ul>	<b>Votre cursus antérieur :</b> <ul style="list-style-type: none"> <li><b>année N-1 :</b> Niveau – Lycée, CPGE, L1, L2, L3, M1, M2, IUT, BTS, autre Discipline principale : Biologie / Chimie / Physique, Physique - Chimie / Chimie - Biologie / Autre (précisez)</li> <li><b>année N-2 :</b> Niveau - Lycée, CPGE, L1, L2, L3, M1, M2, IUT, BTS, autre Discipline principale : Biologie / Chimie / Physique, Physique - Chimie / Chimie - Biologie / Autre (précisez)</li> </ul>
	<b>Did you consult the CHIMACTIV website during this course?</b> Yes / No	<b>Avez-vous consulté le site CHIMACTIV durant cet enseignement ?</b> Oui / Non
	<b>If yes, how many times did you consult the website during this course?</b> 1 time / 2–5 times / 6–10 times / 11 times or more	<b>Si oui, nombre de consultations durant cet enseignement :</b> 1 fois / 2 à 5 fois / 6 à 10 fois / 11 fois ou plus
	<b>If yes, average time spent per consultation during this course:</b> <2 min; 2–5 min; 5–15 min; 15–30 min; 30 min–1 h; >1 h	<b>Si oui, temps moyen de consultation durant cet enseignement :</b> < 2min ; 2 à 5 min ; 5 à 15 min ; 15 à 30 min ; 30 min à 1h ; > 1h

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**Table A.2:** details of the second section related to self-efficacy in our questionnaire. Changes made to the wording of the ESE questionnaire to incorporate the effect of the CHIMACTIV website are detailed (cf. modified ESE), and its French translation used in our questionnaire is presented. The self-efficacy definition and explanation provided for our students at the beginning of this section is also indicated.

<b>Self-efficacy belief definition and explanation</b>			
<p>"Self-efficacy: a person's judgement of their ability to organize and use the various activities necessary to accomplish a task."            "A student's level of self-efficacy reflects the beliefs about their abilities to successfully complete an action."            Your level of self-efficacy can influence your behavior both before and during a task.</p>			
<b>French translation of the self-efficacy belief definition and explanation</b>			
<p>« Sentiment d'auto-efficacité : jugement que porte une personne sur sa capacité d'organiser et d'utiliser les différentes activités inhérentes à la réalisation d'une tâche à exécuter. »            « Le niveau de sentiment d'auto-efficacité d'un élève reflète sa croyance à pouvoir accomplir une tâche dans un domaine donné. »            Votre niveau de sentiment d'auto-efficacité peut ainsi modifier votre comportement avant et pendant une tâche.</p>			
<b>Dimension</b>	<b>Original ESE questionnaire</b>	<b>Modified ESE questionnaire</b>	<b>French translation of the modified ESE questionnaire</b>
Conceptual understanding	Q1- I believe I have a sound grasp of the theory behind laboratory experiments before performing experiments.	Q1- Thanks to the CHIMACTIV website, I believe I have a better sound grasp of the theory behind laboratory experiments before performing experiments	Q1- Grâce au site CHIMACTIV je crois avoir une meilleure compréhension de la théorie sous-jacente aux expériences de laboratoire avant de les réaliser
	Q2- Experimental concepts become clearer to me as I perform the experiment	Q2- More frequently with the help of CHIMACTIV, experimental concepts become clearer to me as I perform the experiment.	Q2- Avec l'aide de CHIMACTIV les concepts expérimentaux m'apparaissent plus clairs quand je réalise les expériences.
	Q3- I am confident that I understand the underlying chemical phenomena in the experiment.	Q3- Thanks to the CHIMACTIV resources, I am more confident that I understand the underlying chemical phenomena in the experiment.	Q3- Grâce aux ressources CHIMACTIV je suis plus confiant-e dans ma compréhension des phénomènes chimiques sous-jacents aux expériences.
Laboratory hazards	Q4- I can usually handle the glass apparatus in the laboratory on my own without any fear of breakage and injury.	Q4- Thanks to the CHIMACTIV website, I can usually better handle the glass apparatus in the laboratory on my own without any fear of breakage and injury.	Q4- Grâce au site CHIMACTIV je peux généralement mieux manipuler la verrerie par moi-même au laboratoire sans crainte de casse ou de blessure.
	Q5- I am confident of working in the laboratory without chemical spillage.	Q5- After having consulted the CHIMACTIV resources, I am more confident of working in the laboratory without chemical spillage.	Q5- Après avoir consulté les ressources CHIMACTIV je me sens plus en confiance pour travailler dans le laboratoire sans renverser de produits chimiques.
	Q6- I am always alert in the laboratory and have minimal accidents	Q6- By consulting the CHIMACTIV website, I am always more alert in the laboratory and have fewer minimal accidents.	Q6- En consultant le site CHIMACTIV je suis toujours plus vigilant-e au laboratoire et j'ai moins d'accidents mineurs.
Procedural complexity	Q7- After an experiment, I have no difficulty figuring out how my calculation procedures and errors affected my results	Q7- More frequently with the help of CHIMACTIV, after an experiment I have no difficulty figuring out how my calculation procedures and errors affected my results.	Q7- Avec l'aide de CHIMACTIV, après une expérience je n'ai pas de difficulté à comprendre comment mes procédures de calcul et mes erreurs ont affecté mes résultats.
	Q8- When presented with laboratory results, I know how to interpret them and draw relevant conclusions from them	Q8- Thanks to the CHIMACTIV website, when presented with laboratory results, I know better how to interpret them and draw relevant conclusions from them.	Q8- Grâce à CHIMACTIV, lorsque l'on me présente des résultats de laboratoire, je sais mieux comment les interpréter et en tirer des conclusions pertinentes.
	Q9- I do not struggle with processing information in background articles and	Q9- More frequently with the help of CHIMACTIV, I do not struggle with processing information in	Q9- Avec l'aide de CHIMACTIV je n'ai pas de mal à traiter les informations contenues dans des documents de

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	relating them to my own laboratory procedures and results.	background articles and relating them to my own laboratory procedures and results.	référence et à les relier à mes propres procédures et résultats de laboratoire.
Sufficiency of resources	Q10- I find it easy to complete the exercise in the laboratory even though there is limited personal participation in performing experiments.	Q10- Thanks to the CHIMACTIV website, I find it easier to complete the exercise in the laboratory even though there is limited personal participation in performing experiments.	Q10- Grâce au site CHIMACTIV il m'est plus facile de réaliser la manipulation en laboratoire, même si ma participation personnelle à la réalisation des expériences est limitée.
	Q11- It is easy for me to understand theory and concepts properly in spite of limited availability of physical instruments	Q11- Thanks to the CHIMACTIV resources, it is easier for me to understand theory and concepts properly in spite of limited availability of physical instruments.	Q11- Grâce aux ressources CHIMACTIV il m'est plus facile de comprendre correctement la théorie et les concepts malgré la disponibilité limitée des appareils.
	Q12- I do not find it challenging to understand an experiment even if there is only one try due to limited availability of chemicals	Q12- More frequently with the help of CHIMACTIV, I do not find it challenging to understand an experiment even if there is only one try due to limited availability of chemicals.	Q12- Avec l'aide de CHIMACTIV je ne trouve pas difficile de comprendre une expérience, même s'il n'y a qu'un seul essai en raison de la disponibilité limitée des produits chimiques.

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**Table A.3:** details of the third section related to anxiety in our questionnaire. Changes made to the wording of the CLAI questionnaire to incorporate the effect of the CHIMACTIV website are detailed (cf. modified CLAI), and its French translation used in our questionnaire is presented. The anxiety definition and explanation provided for our students at the beginning of this section is also indicated.

<b>Anxiety definition and explanation considered in this study</b>			
<p>"Anxiety: an unpleasant (usually temporary) emotional state characterized by feelings of tension, apprehension, nervousness and worry."</p> <p>If you are in an anxious state, you will be more easily distracted, suffer from negative cognitive interference, and this state could have a negative impact on your academic performance.</p>			
<b>French translation of the anxiety definition and explanation</b>			
<p>« Anxiété : état émotionnel désagréable (en général temporaire), se caractérisant par des sentiments de tension, d'appréhension, de nervosité, d'inquiétude. »</p> <p>Si vous êtes dans un état anxieux, vous êtes plus facilement déconcentré(e), vous présentez des interférences cognitives négatives et cet état peut avoir un impact négatif sur vos résultats académiques.</p>			
<b>Dimension</b>	<b>Original CLAI questionnaire</b>	<b>Modified CLAI questionnaire</b>	<b>French translation of the modified CLAI questionnaire</b>
Working with chemicals	Q1- I am anxious when I use chemicals during lab	Q1- Thanks to the CHIMACTIV website, I am less anxious when I use chemicals during lab	Q1- Grâce au site CHIMACTIV je suis moins anxieux ou anxieuse lorsque j'utilise des produits chimiques au laboratoire
Using equipment and procedures	Q2- When I work in the chemistry lab, I feel at ease using the equipment	Q2- When I work in the chemistry lab, I feel more at ease using the equipment thanks to the tutorials and videos of CHIMACTIV	Q2- Quand je travaille dans un laboratoire de chimie, je me sens plus à l'aise dans l'utilisation des appareils grâce aux tutoriels et vidéos de CHIMACTIV
Collecting data	Q3- When I get ready for lab, I get concerned about recording the data we will generate.	Q3- When I get ready for lab, I get less concerned about recording the data we will generate thanks to the CHIMACTIV resources	Q3- Quand je consulte CHIMACTIV pour me préparer à une séance en laboratoire, je suis moins inquiet ou inquiète quant à l'acquisition des données expérimentales que nous allons produire
Working with other students	Q4- When I work in the chemistry lab, I feel nervous working with other students	Q4- When I work in the chemistry lab, I feel less nervous working with other students thanks to the CHIMACTIV website consultation	Q4- Quand je travaille au laboratoire de chimie, je me sens moins nerveux ou nerveuse pour travailler avec d'autres étudiant-es grâce à la consultation du site CHIMACTIV
Having adequate time	Q5- I worry about whether I have enough time to complete the lab.	Q5- Thanks to the CHIMACTIV website, I worry less about whether I have enough time to complete the lab	Q5- Grâce au site CHIMACTIV je me soucie moins de savoir si j'ai assez de temps pour terminer la séance expérimentale ou le TP
Working with chemicals	Q6- When I get ready for chemistry lab, I get concerned about the chemicals we will use	Q6- When I get ready for chemistry lab, I get less concerned about the chemicals we will use thanks to the CHIMACTIV resources	Q6- Quand je consulte CHIMACTIV pour me préparer à une séance en laboratoire, je suis moins préoccupé-e par les produits chimiques que nous allons utiliser
Using equipment and procedures	Q7- When working in the chemistry lab, I feel nervous carrying out the lab procedures	Q7- When working in the chemistry lab, I feel less nervous carrying out the lab procedures thanks to the CHIMACTIV resources	Q7- Grâce aux ressources de CHIMACTIV, quand je travaille dans le laboratoire de chimie, je me sens moins nerveux ou nerveuse lorsque je réalise les procédures de laboratoire
Collecting data	Q8- I am anxious when I record data during lab	Q8- With the help of CHIMACTIV, I am less anxious when I record data during lab	Q8- Avec l'aide de CHIMACTIV je suis moins anxieux ou anxieuse lorsque j'acquiers des données expérimentales pendant la séance en laboratoire
Working with other students	Q9- I feel comfortable working with other students when I am in lab	Q9- I feel more comfortable working with other students when I am in lab thanks to the CHIMACTIV website consultation	Q9- Je me sens plus à l'aise de travailler avec d'autres étudiant-es lorsque je suis en laboratoire grâce à la consultation du site CHIMACTIV

Having adequate time	Q10- When working in the lab, I am nervous about the time it will take	Q10- When working in the lab, I am less nervous about the time it will take thanks to the CHIMACTIV resources	Q10- Lorsque je travaille au laboratoire, je suis moins nerveux ou nerveuse quant au temps que cela va prendre grâce aux ressources de CHIMACTIV
Working with chemicals	Q11- I am comfortable being near chemicals when I am in lab	Q11- With the help of CHIMACTIV, I am more comfortable being near chemicals when I am in lab	Q11- Avec l'aide de CHIMACTIV je suis plus à l'aise d'être à proximité de produits chimiques lorsque je suis au laboratoire
Using equipment and procedures	Q12- I am anxious when I carry out a lab procedure	Q12- I am less anxious when I carry out a lab procedure thanks to the tutorials and videos of CHIMACTIV	Q12- Je suis moins anxieux ou anxieuse lorsque je réalise une procédure de laboratoire grâce aux tutoriels et aux vidéos de CHIMACTIV
Collecting data	Q13- When working in the chemistry lab, I feel nervous about recording the data I will need	Q13- When working in the chemistry lab, I feel less nervous about recording the data I will need thanks to the CHIMACTIV resources	Q13- Grâce aux ressources CHIMACTIV, lorsque je travaille au laboratoire de chimie, je me sens moins nerveux ou nerveuse à l'idée d'acquérir les données expérimentales dont j'aurai besoin
Working with other students	Q14- I feel anxious when I work with other students during lab	Q14- With the help of CHIMACTIV, I feel less anxious when I work with other students during lab	Q14- Avec l'aide de CHIMACTIV je me sens moins anxieux ou anxieuse lorsque je travaille avec d'autres étudiant-es en laboratoire
Having adequate time	Q15- When preparing for lab, I am concerned about the time available for doing the experiment	Q15- When preparing for lab by consulting the CHIMACTIV website, I am less concerned about the time available for doing the experiment	Q15- Quand je consulte CHIMACTIV pour me préparer à une séance en laboratoire, je suis moins préoccupé-e par le temps mis à ma disposition pour réaliser les expériences
Working with chemicals	Q16- When working in the chemistry lab, I feel nervous being around the chemicals	Q16- When working in the chemistry lab, I feel less nervous being around the chemicals thanks to the CHIMACTIV resources	Q16- Lorsque je travaille au laboratoire, je me sens moins nerveux ou nerveuse d'être à proximité de produits chimiques grâce aux ressources CHIMACTIV
Using equipment and procedures	Q17- I feel anxious when I use equipment during lab	Q17- I feel less anxious when I use equipment during lab thanks to the tutorials and videos of CHIMACTIV	Q17- Je me sens moins anxieux ou anxieuse lorsque j'utilise des appareils en laboratoire grâce aux tutoriels et vidéos de CHIMACTIV
Collecting data	Q18- When working in the chemistry lab, I feel at ease recording the necessary data	Q18- When working in the chemistry lab, I feel more at ease recording the necessary data thanks to the CHIMACTIV resources	Q18- Lorsque je travaille au laboratoire de chimie, je me sens plus à l'aise pour acquérir les données expérimentales nécessaires grâce aux ressources de CHIMACTIV
Working with other students	Q19- When I get ready for chemistry lab, I get concerned about working with other students	Q19- When I get ready for chemistry lab by consulting the CHIMACTIV resources, I get less concerned about working with other students	Q19- Quand je me prépare pour le labo de chimie en consultant les ressources CHIMACTIV, je suis moins préoccupé-e par travailler avec d'autres étudiant-es
Having adequate time	Q20- I am comfortable with the amount of time available for doing the lab	Q20- With the help of CHIMACTIV, I am more comfortable with the amount of time available for doing the lab	Q20- Avec l'aide de CHIMACTIV je suis plus à l'aise avec le temps disponible pour réaliser les expériences



**Table A.4:** details of experiments carried out during the practical sessions, for each cohort considered. View Article Online  
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Cohort code	Aim of the practical sessions	Key experiments carried out by the students
1	Analyze a mineral or tap water using various analytical techniques	Electrical conductivity determination Water hardness quantification by titration Calcium and magnesium ions quantification by titration Fluoride, nitrate and sodium ions quantification using specific electrodes Dissolved oxygen determination by titration (Winkler's method) Chloride and sulfate ions quantification by titration Ion concentration quantification by reflectometry Hydrogenocarbonate ions determination by titration
2	Acquire expertise in reproducing existing experimental procedures (the aims are freely chosen by the students), in order to be able to propose them as experimental sessions for their future students	The experimental procedures are freely chosen by the students who are future teachers (e.g. quantification of mineral water hardness by titration, quantification of chloride ions in physiological saline by titration)
3	Acquire expertise in sample preparation, chromatographic techniques as well as detection methods for quantification and/or identification, based on illustrative case studies	Extraction of limonene from orange peel and quantification by GC-FID (internal calibration) or GC-MS (standard additions and internal calibration) Liquid extraction and identification by GC-MS of volatile compounds in citrus juice (orange and lemon) and orange peel Determination of vanillin and ethyl vanillin in vanilla-flavored sugars by HPLC- UV/DAD (external calibration) after solid phase extraction Separation and detection of polycyclic aromatic hydrocarbons by HPLC-UV/DAD-FLD Ethanol content determination in alcoholic beverages using FTIR spectroscopy (external and standard addition calibration) Quantification of compounds in a binary mixture using absorption spectroscopy
4 and 5	Check the nutritional composition of a biscuit	Dry matter determination Protein quantification using Kjeldahl method Lipid quantification after Soxhlet extraction Fatty acid profile by GC-MS Vitamin E quantification by HPLC- UV/DAD-FLD
	Identify the heat treatment applied to vegetable oils rich in omega-3	Acid index by titrimetry Iodine value by titrimetry Peroxide value by titrimetry Tocopherols quantification by HPLC- UV/DAD-FLD
	Find solutions to limit enzymatic browning in apple puree, and explain the mechanisms involved	Formulation of apple purees pH measurement of a suspension Color measurement of suspensions using Lab* colorimetry Extraction of polyphenol oxidases from apples Measurement of PPO activity from apples in absence/presence of enzymes inhibitors
6	Determine the pollutant (diflofenac) concentration in a surface water	Standards' preparation for the calibration curve Solid-phase extraction of the pollutant Extract concentration using nitrogen flow Diclofenac quantification by HPLC- UV/DAD (external calibration)

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**Table A.5:** descriptive statistics for all the data collected relative to self-efficacy (cohorts 2-6; 76 students)  
View Article Online  
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Question	Mean	Median	Standard deviation	Skewness	Kurtosis
Q1- Thanks to the Chimactiv website, I believe I have a better sound grasp of the theory behind laboratory experiments before performing experiments	4.24	4.00	0.67	-0.32	-0.77
Q2- More frequently with the help of Chimactiv, experimental concepts become clearer to me as I perform the experiment.	4.24	4.00	0.69	-0.35	-0.85
Q3- Thanks to the Chimactiv resources, I am more confident that I understand the underlying chemical phenomena in the experiment.	4.00	4.00	0.77	-0.37	-0.27
Q4- Thanks to the Chimactiv website, I can usually better handle the glass apparatus in the laboratory on my own without any fear of breakage and injury.	3.61	4.00	1.12	-0.39	-0.58
Q5- After having consulted the Chimactiv resources, I am more confident of working in the laboratory without chemical spillage.	3.42	3.00	1.15	-0.35	-0.54
Q6- By consulting the Chimactiv website, I am always more alert in the laboratory and have fewer minimal accidents.	3.57	4.00	1.06	-0.35	-0.32
Q7- More frequently with the help of Chimactiv, after an experiment I have no difficulty figuring out how my calculation procedures and errors affected my results.	3.58	3.50	0.98	-0.10	-0.60
Q8- Thanks to the Chimactiv website, when presented with laboratory results, I know better how to interpret them and draw relevant conclusions from them.	3.67	4.00	1.01	-0.32	-0.62
Q9- More frequently with the help of Chimactiv, I do not struggle with processing information in background articles and relating them to my own laboratory procedures and results.	3.59	4.00	0.88	-0.29	0.00
Q10- Thanks to the Chimactiv website, I find it easier to complete the exercise in the laboratory even though there is limited personal participation in performing experiments.	3.72	4.00	0.96	-0.43	-0.28
Q11- Thanks to the Chimactiv resources, it is easier for me to understand theory and concepts properly in spite of limited availability of physical instruments.	3.99	4.00	0.76	-0.17	-0.72
Q12- More frequently with the help of Chimactiv, I do not find it challenging to understand an experiment even if there is only one try due to limited availability of chemicals.	3.83	4.00	0.84	0.06	-1.04

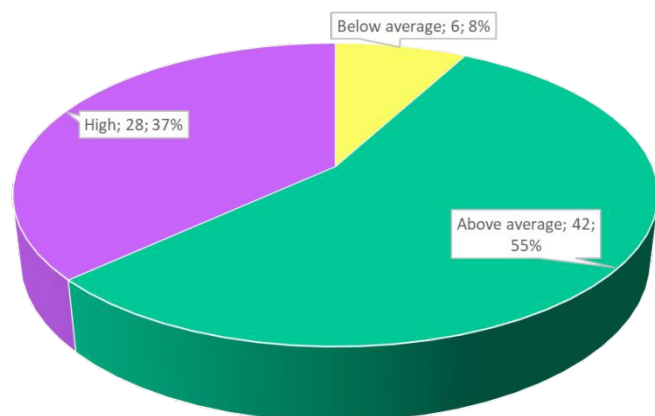
**Table A.6:** descriptive statistics for all the data collected relative to anxiety (all cohorts; 89 students).View Article Online  
DOI: 10.1039/D6RP00091F

Question	Mean	Median	Standard deviation	Skewness	Kurtosis
Q1- Thanks to the Chimactiv website, I am less anxious when I use chemicals during lab	3.24	3.00	1.07	-0.03	-0.37
Q2- When I work in the chemistry lab, I feel more at ease using the equipment thanks to the tutorials and videos of Chimactiv	3.85	4.00	0.83	-0.44	0.39
Q3- When I get ready for lab, I get less concerned about recording the data we will generate thanks to the Chimactiv resources	3.70	4.00	0.90	-0.32	-0.12
Q4- When I work in the chemistry lab, I feel less nervous working with other students thanks to the Chimactiv website consultation	3.38	3.00	1.12	-0.31	-0.45
Q5- Thanks to the Chimactiv website, I worry less about whether I have enough time to complete the lab	3.12	3.00	1.14	0.28	-0.80
Q6- When I get ready for chemistry lab, I get less concerned about the chemicals we will use thanks to the Chimactiv resources	3.24	3.00	1.12	0.02	-0.46
Q7- When working in the chemistry lab, I feel less nervous carrying out the lab procedures thanks to the Chimactiv resources	3.52	4.00	1.01	-0.25	-0.50
Q8- With the help of Chimactiv, I am less anxious when I record data during lab	3.43	3.00	1.03	-0.05	-0.39
Q9- I feel more comfortable working with other students when I am in lab thanks to the Chimactiv website consultation	3.33	3.00	1.13	-0.04	-0.59
Q10- When working in the lab, I am less nervous about the time it will take thanks to the Chimactiv resources	3.14	3.00	1.10	0.04	-0.53
Q11- With the help of Chimactiv, I am more comfortable being near chemicals when I am in lab	3.25	3.00	0.98	-0.00	0.04
Q12- I am less anxious when I carry out a lab procedure thanks to the tutorials and videos of Chimactiv	3.76	4.00	0.87	-0.48	0.25
Q13- When working in the chemistry lab, I feel less nervous about recording the data I will need thanks to the Chimactiv resources	3.47	3.00	0.91	-0.34	0.51
Q14- With the help of Chimactiv, I feel less anxious when I work with other students during lab	3.24	3.00	1.10	-0.06	-0.41
Q15- When preparing for lab by consulting the Chimactiv website, I am less concerned about the time available for doing the experiment	3.26	3.00	1.08	0.01	-0.82
Q16- When working in the chemistry lab, I feel less nervous being around the chemicals thanks to the Chimactiv resources	3.34	3.00	1.04	-0.11	-0.34
Q17- I feel less anxious when I use equipment during lab thanks to the tutorials and videos of Chimactiv	3.69	4.00	0.92	-0.30	-0.29
Q18- When working in the chemistry lab, I feel more at ease recording the necessary data thanks to the Chimactiv resources	3.57	3.00	0.96	0.02	-0.62
Q19- When I get ready for chemistry lab by consulting the Chimactiv resources, I get less concerned about working with other students	3.38	3.00	1.15	-0.16	-0.73
Q20- With the help of Chimactiv, I am more comfortable with the amount of time available for doing the lab	3.43	3.00	1.10	-0.23	-0.58

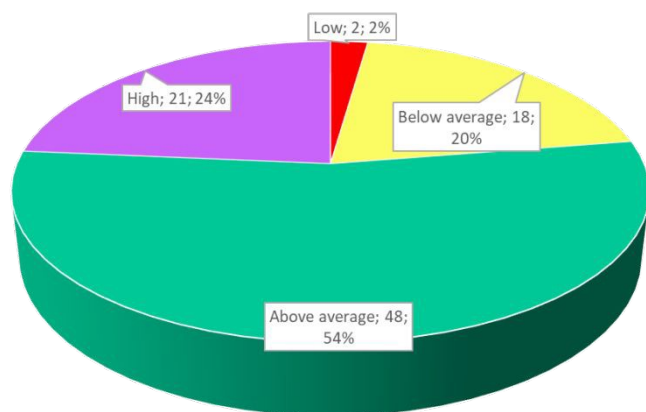
**Table A.7:** Spearman rho correlations between the dimensions of chemistry laboratory self-efficacy and anxiety reduction explored in this study (data from cohorts 2 to 6; 76 students). Values above 0.50 are indicated in bold character (\*\* significance level of 1%).

Correlations considered	Rho values	p- values
conceptual understanding (self-efficacy) - using equipment and procedures (anxiety)	<b>0.54**</b>	3.7x10 <sup>-7</sup>
conceptual understanding (self-efficacy) – working with chemicals (anxiety)	0.44**	6.1x10 <sup>-5</sup>
conceptual understanding (self-efficacy) – collecting data (anxiety)	0.48**	1.4x10 <sup>-5</sup>
conceptual understanding (self-efficacy) – having adequate time (anxiety)	0.41**	2.0x10 <sup>-4</sup>
conceptual understanding (self-efficacy) - working with other students (anxiety)	0.47**	2.0x10 <sup>-5</sup>
procedural complexity (self-efficacy) – using equipment and procedures (anxiety)	0.40**	3.0x10 <sup>-4</sup>
procedural complexity (self-efficacy) – working with chemicals (anxiety)	0.40**	4.0x10 <sup>-4</sup>
procedural complexity (self-efficacy) – collecting data (anxiety)	0.48**	9.4x10 <sup>-6</sup>
procedural complexity (self-efficacy) – having adequate time (anxiety)	0.41**	3.0x10 <sup>-4</sup>
procedural complexity (self-efficacy) – working with other students (anxiety)	<b>0.54**</b>	6.5x10 <sup>-7</sup>
laboratory hazards (self-efficacy) – working with chemicals (anxiety)	<b>0.65**</b>	2.2x10 <sup>-10</sup>
laboratory hazards (self-efficacy) - using equipment and procedures (anxiety)	<b>0.52**</b>	1.3x10 <sup>-6</sup>
laboratory hazards (self-efficacy) – collecting data (anxiety)	<b>0.54**</b>	6.4x10 <sup>-7</sup>
laboratory hazards (self-efficacy) – having adequate time (anxiety)	0.40**	4.0x10 <sup>-4</sup>
laboratory hazards (self-efficacy) - working with other students (anxiety)	<b>0.53**</b>	1.0x10 <sup>-6</sup>
sufficiency of resources (self-efficacy) - using equipment and procedures (anxiety)	<b>0.68**</b>	2.3x10 <sup>-11</sup>
sufficiency of resources (self-efficacy) - working with chemicals (anxiety)	<b>0.59**</b>	1.9x10 <sup>-8</sup>
sufficiency of resources (self-efficacy) - collecting data (anxiety)	<b>0.60**</b>	1.2x10 <sup>-8</sup>
sufficiency of resources (self-efficacy) - having adequate time (anxiety)	<b>0.52**</b>	1.7x10 <sup>-6</sup>
sufficiency of resources (self-efficacy) – working with other students (anxiety)	<b>0.60**</b>	1.4x10 <sup>-8</sup>

**Figure A.1:** classification of the individual scores obtained for the experimental self-efficacy (76 students): 12 to 23 points (low self-efficacy), 24 to 35 points (below average self-efficacy), 36 to 47 points (above average self-efficacy), 48 to 60 points (high self-efficacy). For each category, values indicated are the number of students concerned and their corresponding percentage considering the total of students.

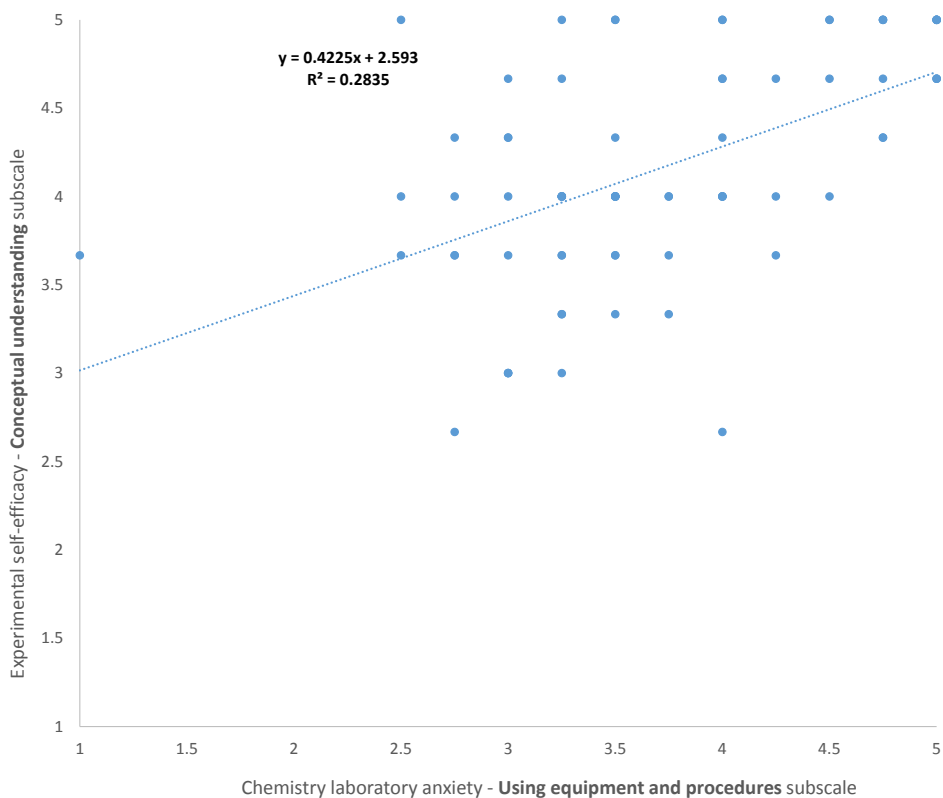


**Figure A.2:** classification of the individual scores obtained for the chemistry laboratory anxiety (89 students): 20 to 39 points (low anxiety reduction), 40 to 59 points (below average anxiety reduction), 60 to 79 points (above average anxiety reduction), 80 to 100 points (high anxiety reduction). For each category, values indicated are the number of students concerned and their corresponding percentage considering the total of students.

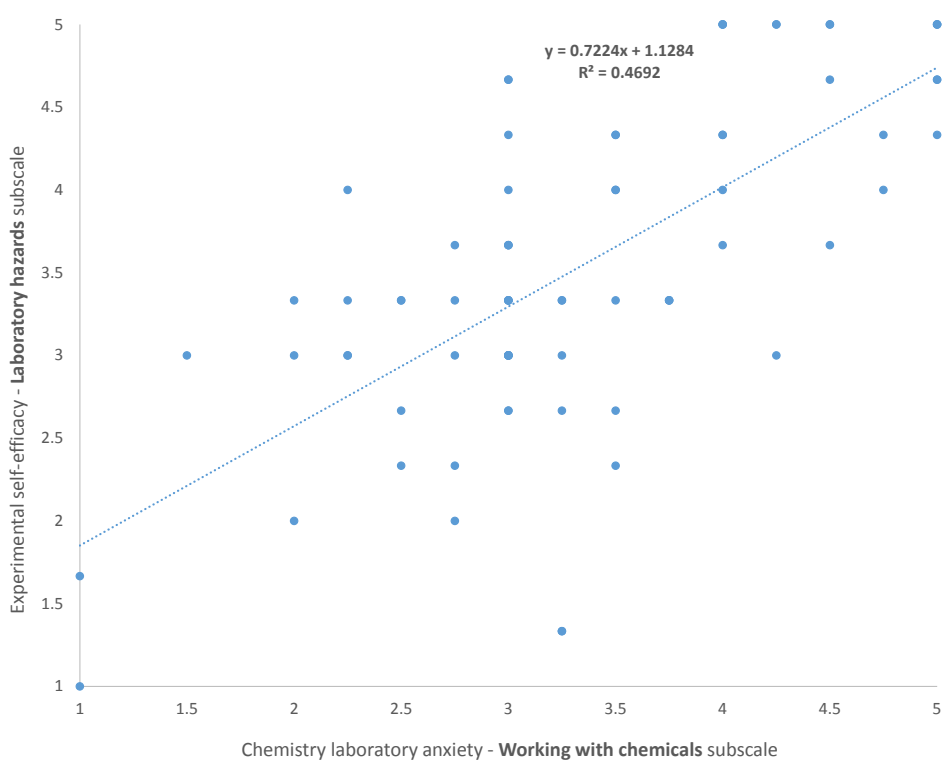


**Figure A.3:** graphs showing different subscale correlations (cohorts 2-6; 76 students).View Article Online  
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Subscale correlation: conceptual understanding (self-efficacy) - using equipment and procedures (anxiety)

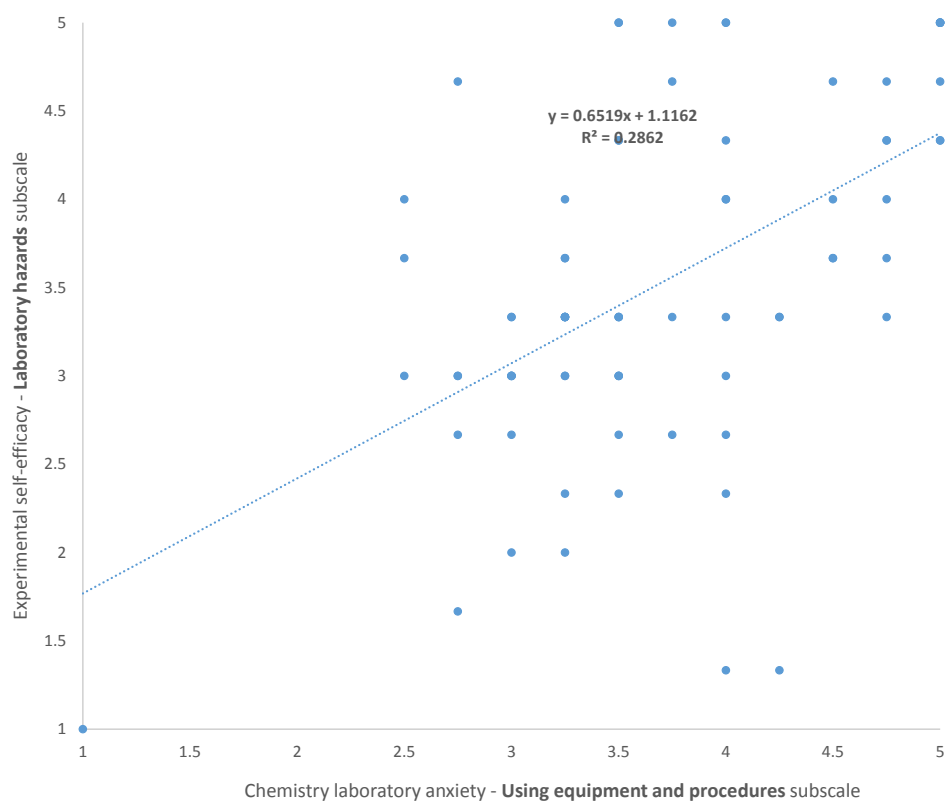


Subscale correlation: laboratory hazards (self-efficacy) – working with chemicals (anxiety)

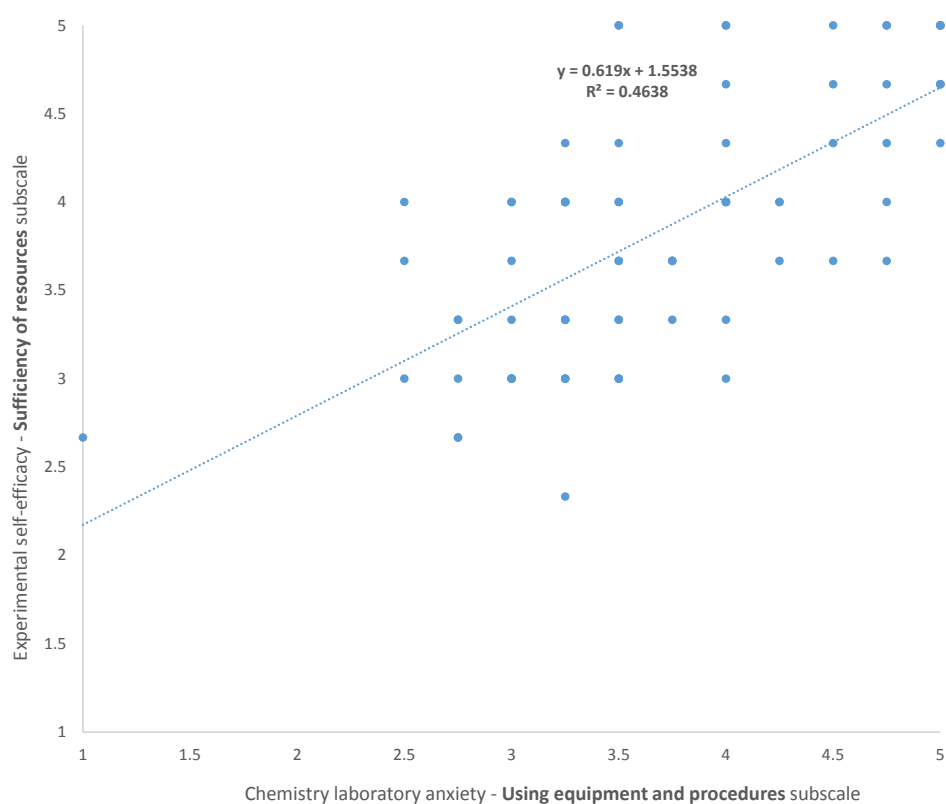


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Subscale correlation: laboratory hazards (self-efficacy) - using equipment and procedures (anxiety)

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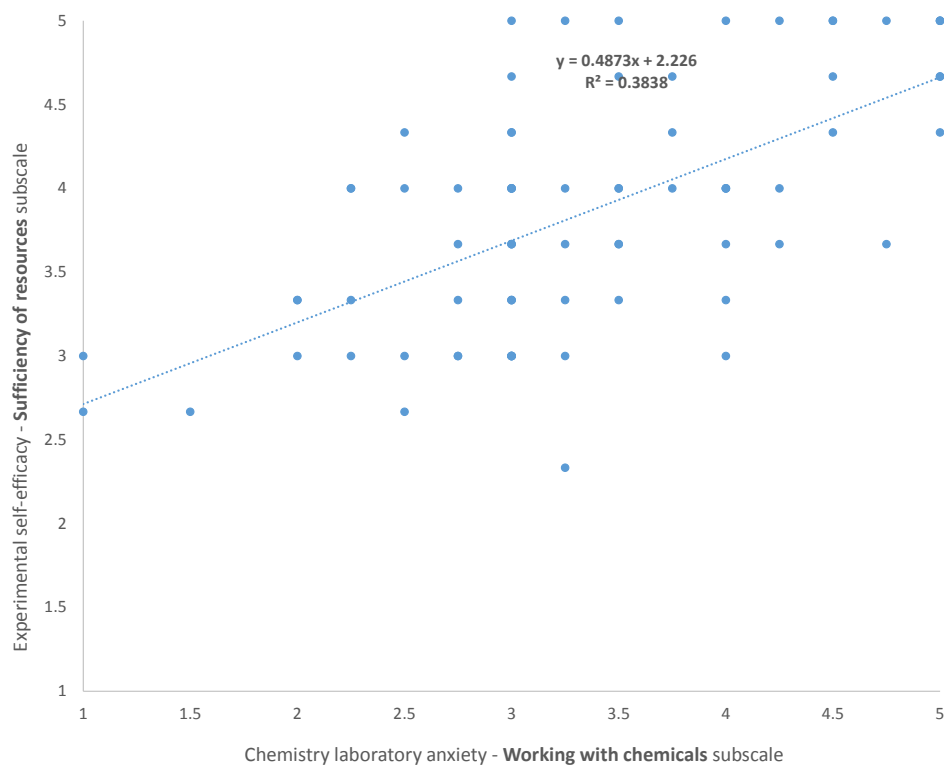
Subscale correlation: sufficiency of resources (self-efficacy) - using equipment and procedures (anxiety)



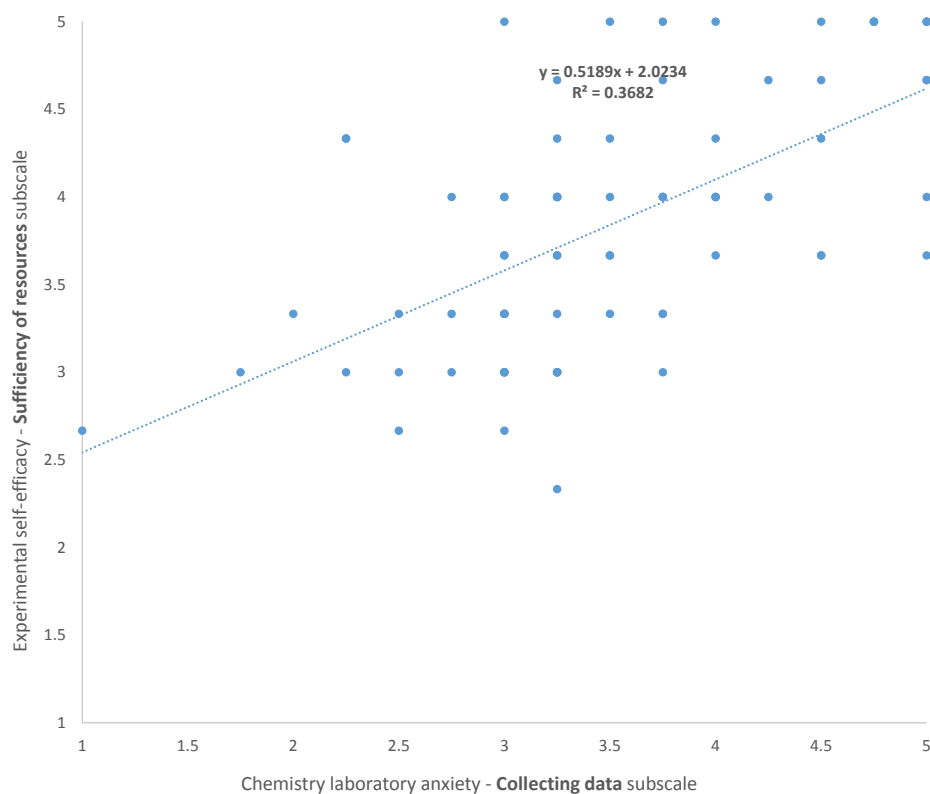
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Subscale correlation: sufficiency of resources (self-efficacy) - working with chemicals (anxiety)

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Subscale correlation: sufficiency of resources (self-efficacy) – collecting data (anxiety)



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## Data availability statement

### Does consulting open online educational resources to prepare for laboratory learning affect students' perception of their experimental self-efficacy and chemistry laboratory anxiety?

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#### Data availability

The data supporting this article have been included as part of the Supplementary Information. In addition, raw data may be deposited on an open access repository if this is of interest to the teaching or scientific community.

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Supplementary Information available: Tables A.1 to A.7 and Figures A.1 to A.3 are given in the Appendix.

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