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Biomedical students' satisfaction with and engagement in laboratory e-learning support are related to their self-regulation

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Abstract

Laboratory e-learning support tools can assist students' learning while preparing for laboratory classes. To successfully work in such virtual experimental environments (VEEs) outside class, students require self-regulated learning (SRL) skills. A deeper understanding of the continuous reciprocal interactions between SRL, satisfaction, and online engagement is needed to develop more effective online learning experiences. This study therefore aimed to explore the interconnection between students' satisfaction with, effort/importance and engagement in an exemplary VEE, and to relate this to their perceived SRL and learning outcomes. Based on surveys in 79 university students, SRL was related to VEE engagement, effort/importance, and satisfaction. VEE engagement and satisfaction were not related to learning outcomes, while SRL and effort were. Students with different SRL also tended to interact differently with the VEE and experienced differing degrees of procedural and feedback support by the e-environment. We conclude that, for optimal learning experience and outcomes, students' effort regulation and SRL need to be supported while interacting with the VEE, preferably by interventions that integrate personalized and adaptive features. This study has implications for designing and optimizing VEEs and indicates that future research should focus on VEEs taking students' SRL and effort regulation into account to support individual learners effectively.

KEYWORDS

e-learning, engagement, laboratory support, satisfaction, self-regulation, virtual experiment

1 | INTRODUCTION

Laboratory activities have a central role in the science curriculum. They aim to enhance students' understanding of, and interest in, scientific concepts and procedures, and to provide hands-on experience with scientific and research tools and skills.[1,2] Students who are better prepared for laboratory activities are more likely to gain the maximum possible benefit from the laboratory learning environment. Benefits are found in acquiring laboratory skills (e.g., hand and observation skills, the ability to plan experiments, to solve problems at the bench and to interpret experimental data) and in terms of learning outcomes (e.g., grade for laboratory journal, experimental report, and participation).[3–6]

Nowadays, flipped e-learning or online laboratory classrooms are common in science education. The increasing availability of e-learning environments and learning management or support systems has launched the deployment of various methodologies to help students prepare for and successfully conduct research during their laboratory classes.[7] Such e-learning tools present opportunities for more personalized and autonomous self-directed learning experiences by providing procedural and metacognitive guidance through integrated closed questions, immediate feedback and hints, by offering contextual information including visualizations and animations, and/or by enabling and guiding the individual or collaborative design of experiments.

In this study, we focus on the laboratory support system LabBuddy® (https://www.labbuddy.net/) as being exemplary for a virtual experiment environment (VEE), defined as “any educational resource that enables students to design and/or carry out virtual experiments and/or to process data, and to analyze and interpret results.”[8] LabBuddy® can create a positive learning experience, support students in achieving the intended learning outcomes and enable students to complete the assignments independently, by integrating experimental background information, photos and videos and allowing students to build a visual overview (flow scheme) representing all steps within the lab experiments to be executed, hereby guided by procedural information, formative feedback and hints.[8] Such VEEs especially can help students to focus on the lower levels of Bloom's revised taxonomy (gaining knowledge and comprehension) outside of class.[9] Consequently, during class, students can be stimulated to focus on the higher cognitive levels (application, analysis, synthesis, and/or evaluation) and motor skills.

It is widely shown that success of computer-based learning is associated with learners' satisfaction, that is, the individuals' perception of the extent to which their needs, goals, and desires have been fully met in the learning environment.[10,11] Previous studies on online learning that attempted to determine the factors influencing student satisfaction, suggested that student satisfaction is related to several aspects such as students' engagement and self-regulated learning (SRL).[11–19] Insight in these relations is crucial to optimally support students' use of e-learning environments.

1.1 | Theoretical framework

Students' learning in a VEE is related to students' positive intent to keep using the environment, that is, students' satisfaction. Davis developed the technology acceptance model (TAM) to explain and predict adoption and use of technology.[20] Perceived usefulness and perceived ease of use are the two main measures to assess the satisfaction, and hence likely acceptance, behavioral intent in, and success of e-learning systems. In an online learning context, perceived usefulness involves the learner's belief that the online learning environment will enhance performance in the course and thus represents extrinsic motivation to use the technology.[21] Perceived ease of use refers to the extent that a learner believes that the use of the particular technology will be relatively easy and thus represents intrinsic motivation to use the technology. Adoption or use of technology is interconnected to a positive attitude toward the system and the behavioral intention to use the system.[21,22]

Although students' satisfaction in terms of perceptions is crucial for the use of e-learning, it is their active involvement that results in their learning and performance. Therefore, engagement is a central concept in our study. Following Martin and Borup (p. 164) we define online learner engagement as: “the productive cognitive, affective, and behavioral energy that a learner exerts interacting with others and learning materials and/or through learning activities and experiences in online learning environments.”[23] Although engagement refers to active behavior, cognitions and emotions, it is always based on an underpinning desire to engage (cf. motivation).[24] A difference between engagement and motivation is the effort regulation that students need to carry out, to transform their desire to behavioral action.[25] Students' engagement includes activities of behavioral, cognitive, and emotional nature and thus demands effort of students. Self-regulated learners allocate effort based on the importance of the items or their interest in it.[26] Effort and importance are therefore often measured as one combined construct “effort/importance.”[27,28] Effort/importance and engagement are related to students' performance and study outcomes.[29–32]

Engagement in online laboratory learning activities, especially when used in flipped or blended set-ups, strongly demands students' SRL.[33,34] SRL refers to students having the control over their own metacognition (e.g., comprehension, application, analysis, synthesis, and or evaluation), motivation (e.g., self-efficacy, persistence), emotions (e.g., enjoyment and boredom) and behavior, helping them to achieve their desired learning outcomes. Different SRL models have been proposed in literature, with Zimmerman's cyclical phase model being the most widely adopted.[35] This model is organized in three phases: forethought, performance and self-reflection. Forethought includes task analysis, that is, goal setting and strategic planning, and self-motivation beliefs, that is, self-efficacy, expectations, task interest, and task value or appreciation. The second phase, regarding performance, includes self-control, that is, time management, attention focusing, effort regulation to engage, persistence, help seeking, environmental structuring, and self-observation or metacognitive monitoring. The self-reflection phase includes self-evaluation and self-reaction, thus initiating a new SRL cycle.

SRL is not only a consequence of learner characteristics but also of supportive digital technologies to stimulate students' use of learning strategies. VEE setup can influence the use of SRL strategies and the VEE, as well as the satisfaction with the VEE.[13,36–40] VEEs can support learners' cyclical SRL phases, for instance by assisting in goal-setting, planning, self-monitoring, and by increasing self-efficacy and engagement. A VEE will be less supportive when learners struggle to select, organize and integrate relevant information, requiring a balanced degree of integrated scaffolding and teacher guidance.[41,42] Also, a multitude of factors such as the use of multimedia, segmentation, hiding of non-important information, the degree of autonomy, the amount and quality of feedback and hints, and the availability of self-monitoring support can influence students' SRL strategies.

1.2 | Study objectives

So far, little is known about how VEEs are appreciated and used by biomedical students and how this relates to students' self-regulation when working in a VEE. This exploratory study aims to contribute to this insight by researching the relationship between students' satisfaction, engagement and effort/importance in an upcoming laboratory education software tool and by relating this to their self-regulation and learning outcomes (i.e., exam grades). More specifically, the objective of this research is to report on the relationship between learner satisfaction, perceived SRL, perceived cognitive/emotional and traced behavioral engagement, and learning outcomes in an exemplary VEE. We formulated the following main research questions:

1. Does perceived SRL affect engagement, effort/importance, and satisfaction? In other words, do students with different perceived SRL report or demonstrate a different experience with the VEE?
2. Are VEE perceived cognitive/emotional and traced behavioral engagement positively related to satisfaction?
3. Are VEE engagement, satisfaction, perceived SRL, and/or effort/importance related to learning outcomes?

This study will inform VEE designers and teachers about differences in students' satisfaction with, and traced behavior in an exemplary VEE. This deeper understanding of the continuous reciprocal interactions between SRL (determined by learner characteristics and the VEE), satisfaction and online engagement will contribute to the development of more effective online learning experiences in the future by supporting individual learners effectively.

2 | METHODS

This study will measure learner satisfaction, perceived SRL, perceived cognitive/emotional engagement, traced behavioral engagement, and learning outcomes in an exemplary VEE. We will focus on the laboratory support system LabBuddy® as being exemplary for a VEE. We will measure students' perceived usefulness and ease of use as indicators for student satisfaction with the VEE. We will take students' engagement as well as their effort/importance into account as relevant variables for students' use of a VEE. Besides measuring students' perceptions, we will measure students' traced behavior as well. For instance, students' time spent in the e-learning environment, the number of clicks and in particular the percentage and the attempts of answered integrated questions, will be considered as indications for students' engagement and effort/importance. To represent all SRL phases, we will take into account goal orientation, strategy use, self-efficacy, and expectations as variables indicating SRL forethought. To represent the performance and self-reflection phase, we will include time management, effort/importance, persistence, engagement, environmental structuring, metacognitive monitoring, and help-seeking. In addition, we will evaluate the VEE variables system feedback and information seeking.

2.1 | Participants

Seventy-nine students that were enrolled in the elective Molecular Pathology course, routinely offered within a BSc biomedical sciences curriculum at a research university in the center of the Netherlands, were recruited by email between 2020 and 2021. The recruited sample represents 93% of the students in the course (79/85 students). The course took place over a period of 10 weeks and included eight half-day temporally separated mandatory practical sessions. The LabBuddy®-based practical experiments started in the first week. Participants represented a fairly homogeneous group based on educational backgrounds with 92% being third year biomedical science students enrolled at our university, aged 20 years on average (SD = 1.1), and gender ratio 48/31 female to male. The study was approved by the Netherlands Association for Medical Education (NVMO) Ethical Review Board (ERB number 2020.6.3). All participants were asked for informed consent. No intervention took place as the participants followed the course with integrated LabBuddy® as usual.

2.2 | Design and procedure

In this exploratory descriptive study, a multi-methods design was used. Within the Molecular Pathology course, LabBuddy® introduction was organized plenary on the first day of the course, with instructors present in case any questions arose. After that, students were asked to prepare for their practical work, using LabBuddy® at home. Within the course, students designed four different laboratory experiments in the experimental environment of LabBuddy®, and subsequently used their experimental designs during real-life practical sessions. A completely virtual experiment was therefore not performed. Using their own acquired experimental data and interpretation, they handed in a scientific paper on three of these experiments as part of their final course grading (50% of final grade). In addition, they kept a lab journal. At the end of the course, there was an exam (40% of final grade) covering theoretical aspects of the entire course, with open questions focusing on the understanding, application and interpretation of molecular techniques, including those performed during their laboratory activities. Writing assignments, exam grades and lab class grade (10% of final grade, including participation and lab journal registration) were used as representatives of course performance.

Participants were asked to fill in a voluntary 10-min survey on LabBuddy® user satisfaction and on their perceived SRL at the beginning of the course (baseline before the first practical session), as well as immediately after the last practical session. These two measuring moments were included to explore how engagement and behavior were related to each other at each time point. Furthermore, the baseline questionnaire was meant to get an overall idea of first impressions and behavioral intent. We also examined correlations between the constructs and differences between baseline and second survey. Of all participants, 74/79 completed the second questionnaire and 55/79 completed both questionnaires. Next, students could voluntarily participate in an additional 30-min semi-structured interview. Eleven students participated.

2.3 | Instrumentation

2.3.1 | Virtual experiment environment LabBuddy®

LabBuddy® (https://www.labbuddy.net) is an e-learning environment that specifically supports learning outside and in laboratory classes. LabBuddy® integrates experimental background information, photos, and videos and allows students to build a visual overview (flow scheme) representing all steps within the experiments to be executed. Figure 1 depicts screenshots of the LabBuddy® e-learning environment designed for the Molecular Pathology course. The module starts with general instructions and a video to learn how to use the experiment designer (ED) that is available in two modi: a "prepare" modus in which students design and prepare their experiments, and a "work" modus that contains all detailed protocols, tips, and tricks needed to successfully perform the experiments. The ED contains a gallery on top, where students can choose from a plethora of molecular techniques, data analysis and data processing methods (Figure 1a). They can connect these items to their experimental workflows by dragging and dropping them to their ED canvas. Information and immediate hints help them in making the correct design. The ED includes background information on the selected experiment, technique or analysis method, experiment goals, available samples, and detailed protocols (Figure 1a).

The experiment introduction and protocols tabs contain integrated closed questions with immediate positive or negative feedback to stimulate and monitor student's understanding. Whenever there is something that requires the student's attention because it is uncompleted (e.g., unanswered question and wrong workflow connection), a blinking signal will appear to guide students in their progress (Figure 1b). Optionally, the tool allows collaboration in small groups where students can simultaneously work on the same scheme. The instructors can approach students' schemes at any time to check for their progress. During lab work, students can approach their flow scheme (on laptop or mobile device), switch from prepare modus to work modus, follow the steps and make notes of their observations in a digital lab journal.

To gain insight into students' behavior in LabBuddy®, we extracted standard user tracking data (editing time,

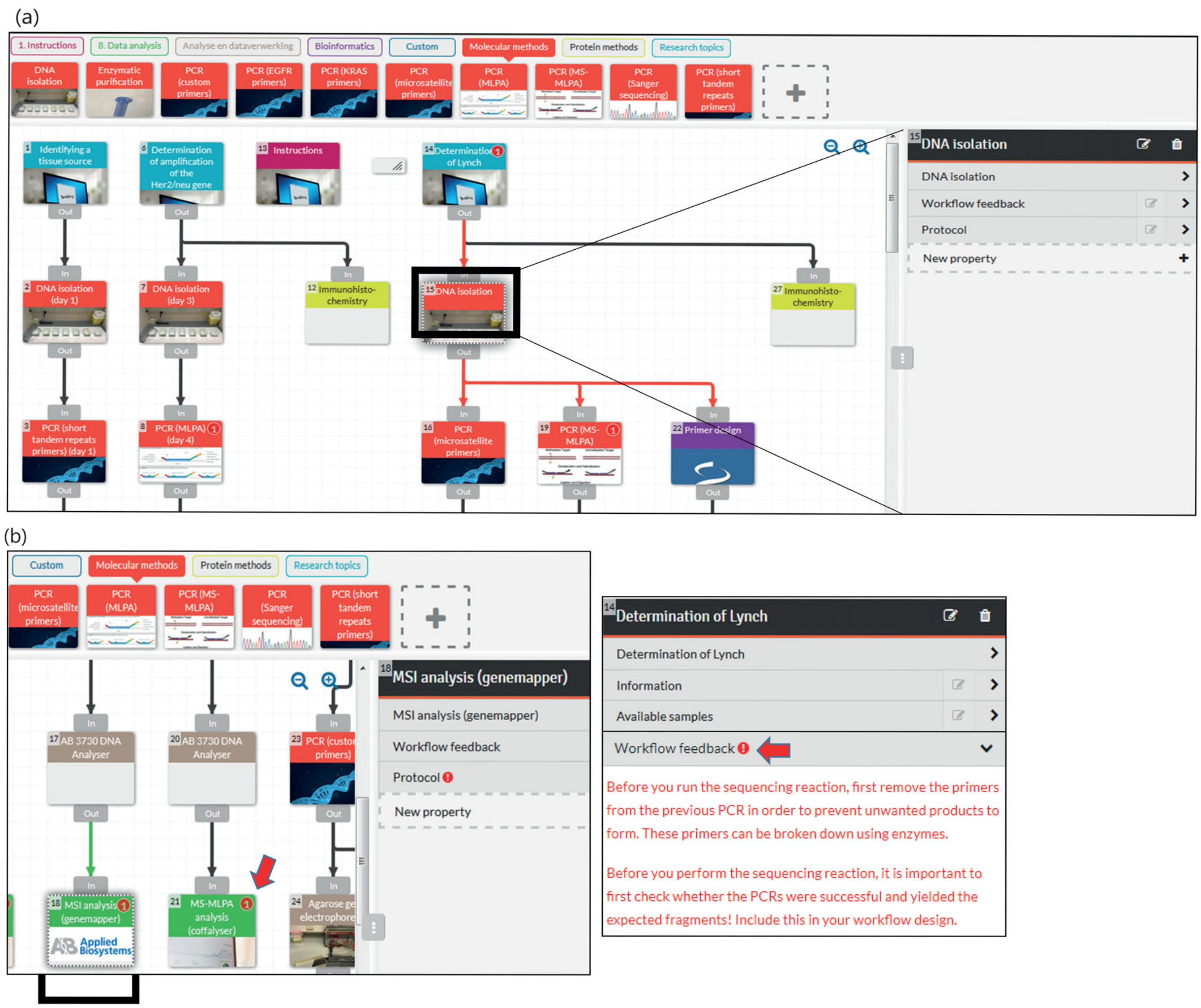

FIGURE 1 LabBuddy® screenshots. (a) Flow scheme with on top a gallery, where students can choose from a plethora of molecular techniques, data analysis, and data processing methods. Students can connect these items to their experimental workflows by dragging and dropping. Tabs on the right include background information on the selected experiment, technique or analysis method, workflow feedback, experiment goals (not shown here), available samples (not shown here), and detailed protocols. Clicking on a specific item (highlighted rectangle) will provide specific information on that experimental step. (b) Whenever there is something that requires a student's attention (e.g., feedback or unanswered question), a blinking signal (arrow) will appear to guide students in their progress. An example of workflow feedback is provided.

number of clicks/connections, velocity, percentage of integrated questions answered and number of tries per question) from the e-learning environment.

2.3.2 | Surveys

Questionnaires were based on a combination of constructs from the validated revised Self-regulated Online Learning Questionnaire (rSROLQ),[38] the motivation questionnaire by Dankbaar et al,[43,44] and the effort/importance subscale of the Intrinsic Motivation Inventory[45] supplemented with items interrogating LabBuddy® satisfaction (usefulness and ease-of-use), perceived competence/self-efficacy, system feedback and behavioral intent (Table S1). Based on the rSROLQ, we included constructs for metacognitive activities before, during and after learning, time management, environmental structuring, and persistence. Based on the motivation questionnaire, we included the construct for engagement. Before applying the questionnaire to a larger audience, a pilot questionnaire was sent out to estimate the response patterns of participants and make any required changes. Besides age, gender, educational background, and estimated time spent in the VEE, the baseline survey included 26 items on perceived first impressions on usefulness, engagement, effort/importance, baseline metacognition, computer self-efficacy (individuals' belief of their capability to perform a specific computer task), behavioral intent as well as intrinsic motivation and self-efficacy for practical sessions. The second survey included 50 items regarding VEE satisfaction (usefulness and ease of use), engagement, system feedback, effort/importance, perceived competence/self-efficacy, and perceived SRL (metacognition before/during/after learning, environmental structuring, time management, and persistence). Four items and the question "Have you worked with Labbuddy® before (yes/no)?" were added at a later stage during the study, leading to fewer responders for these questions. Items were scored on a 5 point Likert scale (1 "strongly disagree" to 5 "strongly agree").

In addition to the questionnaires, voluntary semi-structured interviews were conducted (for model questions and associated themes, see Supplementary Information S1), usually ~1 month after completing the final questionnaire. The aim of the interviews was to explore, among others, students' goals, strategy use in the VEE and the reasons why they did or did not feel better prepared for the practical sessions. The former was categorized into mastery goals (the aim of improving one's own performance and gain task mastery) or performance avoidance goals (the desire to avoid performing more poorly than others do). Of the 11 interviewed students, the female to male ratio was 7/4. Seven of the students had used LabBuddy® for the first time. By estimation, five students had higher perceived SRL capacity, four had intermediate SRL capacity, and two had lower SRL capacity based on their SRL scores.

2.3.3 | Students' course performance: Writing assignments, lab journal, exam

The overall course learning goals were to be able to (1) design and perform molecular biological techniques; (2) analyze and interpret the results; (3) write a research report (including a discussion of obtained results in light of literature); and (4) discuss which technique is most suitable to answer a particular (research/diagnostic) question. To gain insight into student's learning outcomes, we obtained participants' course performance data: grade for practical class (including participation and lab journal registration), grade for practical writing assignments, and grade for final course exam. Supplementary Information S2 shows some sample exam questions.

2.4 | Data analysis

The data gathered through the surveys, behavior data extracted from LabBuddy®, and the course performance data were used for statistical analysis. After pseudonymising, the data were processed into SPSS. For questionnaire data, frequencies, means, standard deviations, and total scores were calculated per item and per construct and indicated as (% score 4 or 5; mean; standard deviation). Factor analysis was not feasible given the small sample size. Hence, a Cronbach's alpha was calculated per construct to estimate the reliability of the scales that measured the constructs. The Cronbach's alphas for the intended perceived usefulness, engagement and behavioral intent scales in the first survey were 0.83, 0.82, and 0.75. The Cronbach's alphas for the intended satisfaction, engagement, effort/importance, and the rSROLQ self-regulation (combined constructs for metacognitive activities, environmental structuring, time management, and persistence) scales in the second survey were 0.82, 0.83, 0.72, and 0.80, respectively, indicating estimated reliability of the scales (Table S1). The mean satisfaction, perceived engagement, effort/importance and SRL score per student, as well as course performance (writing assignments, practical session, exam) and VEE trace data (time spent in the e-learning environment, the number of clicks/connections and the percentage and attempts of answered integrated questions) were used as continuous variables for Pearson correlation analysis. For items present in baseline and final questionnaire, the baseline score was subtracted from the final score and used for correlation analysis as well. Bonferroni correction was applied to correct for multiple comparisons. Correlations were depicted by the R package "corrplot" (version 0.90) using Rstudio version 1.3.1093.

Interviews were, with permission, recorded in MS Teams, transcribed verbatim afterwards, and thematically analyzed.[46] After having carefully read through the transcripts to gain an overall understanding of the material, open codes were determined by theoretical thematic analysis by hand, and organized into initial themes, and iteratively checked in relationship to the whole data set to refine each theme.[47] An example of coding is provided in Supplementary Information S3. The content of open questions from student and instructor surveys were analyzed qualitatively with an open coding system.

3 | RESULTS

3.1 | Students' first impressions and overall satisfaction with the VEE

In baseline and final surveys, ≥ 85% of students indicated to be satisfied with VEE performance, and to feel better prepared compared to other practicals not using the VEE. They particularly appreciated the oversight provided by the VEE. Table S2 shows mean 5-point Likert score, standard deviations and frequencies per score, per item of baseline and final surveys.

Overall, students' first impressions of LabBuddy®'s usefulness were positive (score 3.94 on average). After having used the VEE for several weeks, the majority of students was satisfied with its performance (87%; 4.0; 0.7) and would recommend its use for other practicals as well (88%; 4.2; 0.7). They felt better prepared compared to other practicals not using LabBuddy® (85%; 4.1; 0.8), and especially appreciated the oversight it helped to keep over the experiments (92%; 4.5; 0.7). These results are consistent with findings from the student interviews and the open survey questions. Overlapping reasons of the 82% (9/11) interviewed students that felt better prepared for practicals were: (1) because they felt engaged by the VEE (active process; $n = 6$); (2) because the VEE helped with task analysis (forethought; $n = 3$); (3) because they felt more confident for the practicals (self-motivation beliefs of forethought; $n = 2$). Regarding oversight, 62% (28/45) of students indicated in the open survey questions that this was what they liked most about the VEE. When we asked the interviewees to describe what they meant by "oversight," they mentioned: the structured overview, not per date but per experiment which allowed more easy retrieval of information; the global visual (helicopter) overview; the being able to open and close certain blocks of information so they only saw the information they needed at that specific moment ("prepare" modus); and the being able to gray out steps during the lab experiments ("work" modus).

Aspects that students appreciated most about the VEE based on the open survey questions besides oversight, were the better understanding of the experimental setup (20%), and being stimulated to actively think about the experiment before executing (9%). The usefulness of the prepare modus of the VEE by interviewees was perceived in: the structured overview of what to do, when and why (seeing and keep seeing "the whole" in 1 place) (7×), the integrated questions (3×), the clear and interactive process of discovering why/what (4×), the complete information being provided in collapsable fragments/blocks with clear headers (2×), the confidence it gave, the fact that it was instructive and because of the sufficiently scaffolded autonomy it provided. Consistent with these findings, according to the final questionnaire, the VEE helped increase confidence about practicals (78%; 3.9; 0.7) and encouraged students to start their laboratory classes (72%; 3.7; 0.7).

At the end of the practicals, comparing the final survey to baseline, students were positively surprised about the oversight the VEE provided ($t\ (49) = 5.87$, $p < 0.0001$, $d = 0.83$, 95% CI [0.55–1.11]) and liked the way of learning more than they initially anticipated ($t\ (49) = 3.06$, $p = 0.004$, $d = 0.43$, 95% CI [0.15–0.72]). Consistent with this, for 82% of interviewed students, the VEE met or exceeded their expectations.

In comparison to students using the VEE for the first time ($n = 14$), students having used LabBuddy® before ($n = 12$) were able to concentrate better when using the VEE ($t(23) = -3.06$, $p = 0.006$; $d = 1.23$). They thought they prepared better compared to other students ($t(23) = -2.65$, $p = 0.015$; $d = 1.07$), and felt more encouraged to start the practical sessions ($t(23) = -2.24$, $p = 0.035$; $d = 0.90$). They also more strongly indicated that the VEE helped them control, monitor, and adjust their study behavior and line of reasoning ($t(19) = -2.16$, $p = 0.043$; $d = 0.95$) (Figure S1). There were no significant differences in their traced VEE behavior.

3.2 | The relations between perceived SRL, satisfaction, engagement, and effort/importance

Overall, reported satisfaction and engagement after VEE completion were significantly correlated with baseline perceived usefulness, engagement, and behavioral intent. Perceived SRL after VEE completion was significantly correlated with engagement, satisfaction as well as effort/importance. Satisfaction was also significantly correlated with engagement.

No significant correlations were observed between perceived SRL or effort/importance (measured by second survey) and baseline perceived usefulness, engagement or behavioral intent (all correlations $r < 0.28$). Engagement measured by the second survey, on the other hand, was positively correlated to baseline perceived usefulness ($p < 0.0001$, $r(47) = 0.74$), baseline engagement ($p < 0.0001$, $r(47) = 0.67$) and behavioral intent ($p = 0.001$, $r(47) = 0.46$). Satisfaction was also positively correlated to baseline perceived usefulness ($p < 0.0001$, $r(48) = 0.71$), baseline engagement ($p = 0.0005$, $r(48) = 0.49$), and behavioral intent ($p < 0.0001$, $r(48) = 0.55$).

After working with the VEE for several weeks, students with higher perceived SRL capacity reported to feel generally more engaged ($p = 0.001$; $r(70) = 0.39$); particularly they felt more actively involved) and satisfied with the VEE ($p = 0.012$; $r(73) = 0.29$; Figure 2). Furthermore, effort/importance was significantly higher in students with higher perceived SRL ($p < 0.0001$, $r(73) = 0.67$). Higher SR learners more strongly agreed that the VEE helped control, monitor and adjust their study behavior and line of thought ($p = 0.008$; $r(21) = 0.55$),

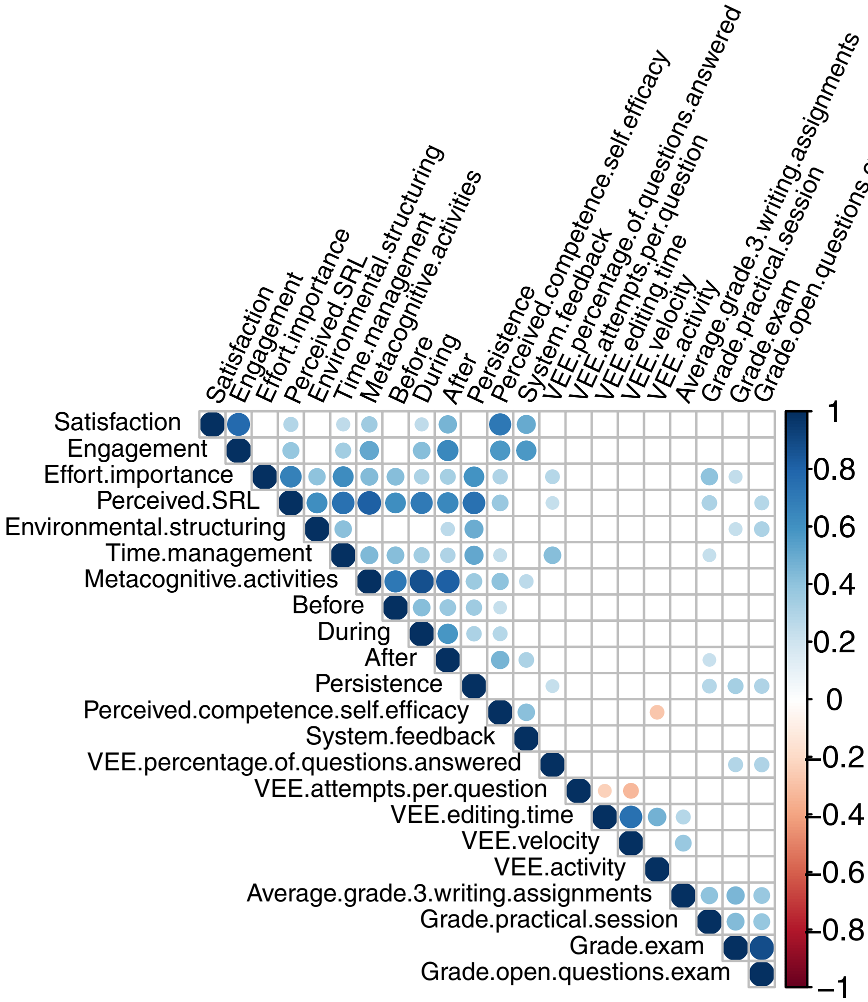

FIGURE 2 Correlation plot showing correlations with $p < 0.05$ between satisfaction, engagement, effort/importance, perceived self-regulated learning (SRL), virtual experimental environment engagement trace data, and learning outcomes. Perceived SRL is represented by its subscales environmental structuring, time management, metacognitive activities before, during and after learning, and persistence. Positive correlations are displayed in blue and negative correlations in red color. Color intensity and the size of the circle are proportional to the correlation coefficients.

and helped them feel more confident about the practicals compared to lower SR learners ($p = 0.005$; $r(73) = 0.33$).

Student satisfaction with the VEE was significantly correlated to reported engagement within the VEE ($p < 0.0001$, $r(71) = 0.77$) and perceived SRL ($p = 0.012$; $r(73) = 0.29$; particularly with metacognitive activities after learning with $r(74) = 0.46$), but not with effort/importance ($p = 0.058$, $r(74) = 0.22$). A significant relation between satisfaction and engagement was only observed in students having used the VEE before ($p = 0.0003$, $r(11) = 0.89$ vs. $p = 0.89$, $r(13) = 0.04$), albeit based on a small subsample of the cohort ($n = 26$). Participants with lower SRL generally perceived the VEE as less user friendly, providing them less oversight and less monitoring capacity than indicated by high SR learners. Nevertheless, all interviewed students, regardless of their self-regulation capacity, agreed that the VEE had helped them with controlling/monitoring to process their study material: it helped them to (inter)actively think about what they were learning, it "pushed" them to better prepare and to monitor their progress, helped repeating course material, provided the study material in fragments, and provided structure and clear study goals.

Student satisfaction was also positively correlated to perceptions on system feedback ($p < 0.0001$, $r(73) = 0.50$) and perceived competence that is self-efficacy ($p < 0.0001$, $r(74) = 0.71$). Regarding system feedback, the majority of interviewed students (64%) was satisfied with the amount of feedback provided by the VEE ("LabBuddy® provided sufficient guidance") and found support in other students (91%) and/or teachers (25%) when needed. Fellow students were preferred because this usually allowed a quicker response, so that learners could immediately continue their learning experience. None of the interviewed students were reluctant to start their workflows or gave up while working on them.

VEE engagement was significantly correlated to satisfaction and perceived SRL but not to effort/importance ($p = 0.052$, $r(71) = 0.23$). Engagement was also significantly positively correlated to perceptions on system feedback ($p < 0.0001$, $r(71) = 0.58$) and to perceived competence that is self-efficacy ($p < 0.0001$, $r(71) = 0.58$).

Furthermore, significant correlations were observed with the SRL aspects metacognitive activities during ($p < 0.0001$, $r(71) = 0.43$) and after learning ($p < 0.0001$, $r(71) = 0.65$). Students who felt more engaged, more strongly indicated that the VEE stimulated them to actively think about what they were doing and why ($p < 0.0001$, $r(53) = 0.61$).

While no significant correlation was found with satisfaction or engagement, effort/importance was significantly higher in students with higher perceived SRL ($p < 0.0001$, $r(73) = 0.67$). An (cautionary) exploration of the subscales indicated that effort/importance was significantly positively correlated to environmental structuring ($p < 0.0001$, $r(74) = 0.41$), time management ($p < 0.0001$, $r(74) = 0.62$), metacognitive activities before ($p < 0.0001$, $r(74) = 0.43$) and after ($p = 0.0003$, $r(74) = 0.34$) learning, and persistence ($p < 0.0001$, $r(73) = 0.60$).

When actual VEE experience was compared to expectations at the beginning of the course, students who felt more encouraged by the VEE to start the practical sessions than initially anticipated showed significantly higher effort/importance ($p = 0.009$, $r(48) = 0.37$) and environmental structuring scores ($p = 0.006$, $r(48) = 0.39$). Environmental structuring was also significantly higher in students who accessed more material in the VEE than envisioned at baseline ($p = 0.002$, $r(50) = 0.42$). Students who eventually perceived more fun to work through the material in the VEE than anticipated, showed significantly higher metacognitive activities after learning ($p = 0.009$, $r(50) = 0.37$), and as expected felt more engaged ($p = 0.006$, $r(49) = 0.39$).

3.3 | Students' VEE behavior related to perceived SRL, satisfaction, engagement, and effort/importance

Figure 2 depicts correlations between perceived SRL, satisfaction, engagement, effort/importance, VEE behavior, and learning outcomes. After correction for multiple comparisons, there were no significant correlations between VEE behavior and the constructs for perceived SRL, satisfaction, engagement, or effort/importance. There was however a significant positive correlation between the time management subscale of perceived SRL and the percentage of questions answered in the VEE ($p = 0.0002$, $r(74) = 0.42$).

The percentage of questions answered in the VEE tended to be (nonsignificantly) positively correlated with perceived SRL ($p = 0.049$, $r(73) = 0.23$), including persistence ($p = 0.046$, $r(73) = 0.23$), and with effort/importance ($p = 0.015$, $r(74) = 0.28$). Furthermore, students with higher behavioral intent at baseline ($p = 0.019$, $r(52) = 0.33$) and showing a positive shift in encouragement for laboratory classes between baseline and final questionnaire ($p = 0.011$, $r(48) = 0.37$) tended to answer more questions in the VEE. The average number of attempts per question tended to be fewer for students who eventually liked the way of learning in the VEE less than anticipated at baseline ($p = 0.015$, $r(49) = -0.35$).

VEE activity (number of clicks and connections) tended to be positively correlated to students' baseline intrinsic motivation for practicals ($p = 0.049$, $r(53) = 0.27$), and negatively correlated to students' perceived competence, that is, self-efficacy ($p = 0.018$, $r(74) = -0.28$) and whether learners received sufficient feedback from the VEE in their opinion ($p = 0.039$, $r(73) = -0.24$).

Students with higher baseline metacognition tended to show lower VEE velocity ($p = 0.014$, $r(53) = -0.34$). The level of baseline confidence in using the VEE without an instructor present and about performing the VEE tasks did not affect VEE behavior, nor did their age, baseline perceptions on the difficulty of the integrated questions or the extent to which they believed the construction of the experimental setup would be challenging.

Regarding the strategy to construct their experimental workflows in the VEE, most interviewed students (7/11; 64%) started from experimental goals (as indicated by LabBuddy®), followed by exploring the different possibilities and a targeted search for suitable next steps (techniques and analysis methods). But upon difficulties, the strategy was often adjusted to trial and error. The other four students immediately initiated trial and error, and later-on adjusted their strategy to a targeted search. Interestingly, three of these four students had higher perceived SRL capacity, while only one of them had lower SRL capacity. Trial and error was related to perceived insufficient feedback from the e-learning environment, or being overwhelmed with information/possibilities at the start of the first workflow.

3.4 | Students' learning outcomes related to perceived SRL, satisfaction, engagement, effort/importance, and VEE behavior

Overall, perceived SRL and effort/importance were positively correlated to learning outcomes (particularly practical grades) while satisfaction and engagement were not. VEE behavior was also positively correlated to learning outcomes, particularly exam grades and grades for writing assignments.

The percentage of questions answered in the VEE was positively correlated to students' exam grades, particularly to the open exam questions ($p = 0.006$, $r(75) = 0.31$) focusing on the understanding, application and interpretation of molecular techniques (Figure 2). VEE editing time ($p = 0.011$, $r(77) = 0.29$) and VEE velocity ($p = 0.001$, $r(77) = 0.38$) were positively correlated to the average grade of all three lab experiment-related writing assignments. VEE satisfaction and engagement were not significantly correlated to learning outcomes (all correlations between $r < -0.15$ and 0.13). Perceived SRL was significantly positively correlated to practical grades ($p = 0.006$, $r(73) = 0.32$) and tended to be correlated to open question exam grades ($p = 0.016$, $r(71) = 0.29$). The former association can be mainly attributed to better time management, metacognitive activities after learning and persistence, the latter to better environmental structuring during VEE usage and persistence. Effort/importance significantly positively correlated to practical grades ($p = 0.0003$, $r(74) = 0.41$) and partly correlated to overall exam grades ($p = 0.041$, $r(72) = 0.24$).

4 | DISCUSSION

This study aimed to explore the mutual relations between students' satisfaction with, perceived effort/importance, perceived engagement, and perceived self-regulation in an exemplary VEE, as well as to examine their connection to learning outcomes.

Here, we utilized the VEE as a preparation tool for hands-on laboratory practice. Comparative studies in the chemistry field have suggested that virtual laboratories are equally effective or sometimes even better than hands-on laboratories regarding declarative knowledge, procedural knowledge, and skill-based outcomes.[48] Nevertheless, the use of virtual experiments as a supplementary tool combined with hands-on practicals was shown to promote self-efficacy, conceptual understanding, procedural, and inquiry skills better than a single type of experimentation.[49,50]

The majority of students was satisfied with VEE performance and especially appreciated the oversight, the integrated questions provided by the application, and the interactive process of discovering why/what/how to perform certain experiments and experimental steps. The environment thus seems to provide metacognitive support (procedural guidance via feedback/hints, monitoring capacity via integrated questions) and manage essential processing (schematic overview, all information in one place, provided exactly when the learner needs it, segmenting in collapsible blocks and time).[51,52] The environment was also reported to increase feelings of autonomy and self-efficacy, known to promote intrinsic and internalized motivations (self-determination theory and social cognitive theory).[45,53–56] It is therefore not surprising that students' satisfaction was significantly positively correlated to competence/self-efficacy, engagement, perceptions on system feedback, and to baseline perceptions on usefulness, baseline engagement and behavioral intent. In relation to perceived self-regulation, students with higher perceived SRL, especially students reporting high metacognitive activities after learning, generally had a more positive perception of the VEE's usefulness and felt more supported. No relation was found between satisfaction, VEE behavior measured by digital trace data,[57,58] or learning outcomes.

VEE engagement showed a highly significant reciprocal positive relationship with satisfaction, and was consequently correlated to the same variables. Again, no significant relation was found between engagement, measurable VEE behavior or learning outcomes.

Effort/importance showed a significant reciprocal positive relationship with perceived self-regulation, consistent with Zimmerman et al,[59] but was not significantly correlated with perceived VEE engagement or satisfaction, nor with baseline behavioral intent, baseline engagement, or baseline perceptions on VEE usefulness (i.e., satisfaction). Effort/importance was significantly positively correlated with learning outcomes but not with traced VEE behavior. Students with higher self-reported effort/importance nevertheless tended to answer more of the VEE integrated questions.

Perceived self-regulation was thus related to all other investigated constructs: effort/importance, engagement, and satisfaction. It influences engagement and satisfaction. Students with higher perceived SRL tended to answer more of the VEE integrated questions, and especially those students with increased environmental structuring and persistence, had better learning outcomes. The association between SRL and learning outcomes confirms previous findings.[60,61] All interviewed students, regardless of their self-regulation capacity, agreed that the VEE had helped them with controlling/monitoring the processing of their study material. This, and the overall high satisfaction, suggests that lower as well as higher self-regulated learners experience some benefit from the e-environment, but students with lower SRL indicated to feel less engaged, satisfied, confident and supported by the VEE, and reported lower effort/importance while preparing for the practical sessions. This suggests that lower SRL learners might require more support (system feedback/monitoring capacity, help while constructing the first workflow, teacher interaction) and encouragement to stimulate effort regulation and consequently, engagement and SRL. This could be achieved by, for example, setting the pace (sending reminders of due dates), having students collaborate in the VEE, by promoting time management (have students create their schedules) and encouraging environmental structuring. The latter two would be of special interest as this study showed a relatively small but significant positive relation between both variables, effort, VEE interaction (percentage of questions answered, accessing of all material), and learning outcomes. The use of sufficient and meaningful hints and seeking information with limited access to ready-made answers, should be encouraged. And to promote SRL, it might also be useful to embed SRL support in the VEE, for example through prompts.[62] Edisherashvili et al recently published a thorough systematic review on phases and areas that can be targeted by SRL support interventions.[63] Whereas metacognition regulation and the performance phase of learning is vastly investigated, the emotion regulation, and the forethought and self-reflection phases of the SRL cycle are somewhat underexplored.

In this study, the percentage of answered VEE questions and the perceived amount and quality of system feedback/hints appear to be very important determinants of metacognitive activities after learning, competence/self-efficacy, engagement, satisfaction, and learning outcomes. An obvious way to increase effort regulation could therefore also be to use a reward system (attach points to these assignments/questions to ensure completion).[64]

Students having used the VEE before in a different context showed similar e-learning behavior compared to other students but felt more encouraged to start the practical sessions and more strongly indicated that the VEE helped them control, monitor, and adjust their study behavior and line of thought. Although based on a small student subcohort, this suggests that the VEE not only engages and supports because it is experienced as new and exciting, but even becomes more supportive and encouraging when users get more experienced with the tool. Nevertheless, even in experienced users, there was a positive correlation between self-regulation, VEE engagement, effort/importance, perceived system support (helped control, monitor and adjust study behavior and line of thought), and satisfaction, suggesting that lower SR learners require a more personalized approach.

Although we did not find significant VEE behavioral differences related to SRL, satisfaction, engagement, or effort/importance after correction for multiple comparisons, we did find several possible associations with learner and VEE characteristics at the $p < 0.05$ level. For example, VEE activity (number of clicks and connections) seemed related to self-efficacy beliefs, to system feedback perceptions and previous experience with the VEE. The percentage of questions answered within the VEE appeared related to SRL, effort, baseline behavioral intent, and perceptions on encouragement for practicals while using the system. The number of attempts per question seemed related to affective engagement while using the system ("I like this way of learning"). Hence, the way students engage with the VEE seems to depend on learner characteristics (i.e., SRL/metacognition, affect) and VEE characteristics (i.e., system feedback) and may continuously change while using the VEE (and attending the rest of the course including the practicals), making it difficult to find strong associations with the investigated variables. Ultimately, only the percentage of questions answered in the VEE was correlated to learning outcomes, assumingly via the reciprocal interaction between SRL and effort. These findings suggest that perhaps, in line with Verstege et al, students differ in how effectively they interact with a VEE (e.g., complete the integrated questions),[65] but this requires further confirmation. It should be noted that some of the VEE trace data, especially editing time, activity, and velocity, may not reflect effort/importance and engagement well. Less clicks, for example, could suggest less effort/importance and engagement but could also suggest that a student carefully reads and reflects before showing activity (=more effort/importance and engagement). Associations with these measures should therefore be interpreted with caution. We however believe that the percentage of questions answered and the number of attempts per question in the VEE better reflect actual effort/importance and engagement.

Not only the relatively small number of participants in this study has its limitations for generalizability, but also the fact that e-learning environments have different characteristics and require specific research, since the characteristics and purpose of the environment strongly determine students' behavior.[66] Regarding instrumentation, we used validated questionnaires but in our small sample the assumptions of factor analysis were not met to check for underlying constructs. Not for all subscales within the original questionnaires, a good Cronbach's alpha could be achieved. We therefore focused on the scales satisfaction, engagement, effort/importance and SRL, as well as the subscale metacognitive activities. Correlations reported based on other and smaller subscales should be interpreted with caution. The combination of baseline and final questionnaires with interviews nevertheless strengthens our data. As this was not part of the intended learning outcomes of our course, we did not assess students' wet lab skills and could thus not study how the development of these skills is connected to the investigated variables. Mostly, studies focus on the effect of virtual experimental learning platforms on self-reported experimental self-efficacy, conceptual understanding, procedural and inquiry skills, without including actual wet lab skills. Future studies, especially those based on a course including wet lab skills in their intended learning outcomes, could therefore benefit from including the development of such skills when investigating the impact of laboratory e-learning support. Lastly, it is known that students' recall is not always accurate when reporting their own use of strategies[67] but self-reported data is still regarded as a valid measure of SRL.[35,68]

Collectively, despite its limitations, the current study provides a stepping stone for further research into the design and optimization of laboratory support tools, used in combination with hands-on practicals. We have shown a complex interaction between satisfaction, engagement, effort/importance, self-regulation, VEE behavior, and learning outcomes. Engagement and satisfaction were not related to learning outcomes in this study, while SRL and effort were, implying the need to support students' effort regulation and SRL while interacting with the VEE. Suggestions on how this could be achieved were discussed. Students with different self-regulation also tended to interact differently with the VEE and experienced differing degrees of procedural and feedback support by the e-environment. The difficulty therefore lies within providing sufficient VEE support and feedback to students who need it and at the same time keep the learning experience challenging enough for students who require less VEE support. This suggests that for optimal learning support, interventions that integrate personalized and adaptive features should be considered. So far, most personalized feedback studies in digital learning environments have used current knowledge and learning behavior data as the basis for feedback adaption, while emotional state measures, progress measures, learning goals, or personality traits remain underinvestigated.[69] Although most such personalized feedback studies have reported positive or at least mixed or neutral effects on educational outcomes, still much research is required on proving the right (amount of) feedback at the right time based on the right combination of input variables. Future research should focus on personalized laboratory support tools, taking students' SRL, and effort regulation into account.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data available in article supplementary material.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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