# ACCEPTED MANUSCRIPT

Fostering students' motivation towards learning research skills: the role of autonomy, competence and relatedness support

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**Abstract:** In order to design learning environments that foster students' research skills, one can draw on instructional design models for complex learning, such as the 4C/ID model (van Merriënboer & Kirschner, 2018). However, few attempts have been undertaken to foster students' *motivation* towards learning complex skills in environments based on the 4C/ID model. This study explores the effects of providing autonomy, competence and relatedness support (Deci & Ryan, 2000) in a 4C/ID based online learning environment on upper secondary school behavioral sciences students' cognitive and motivational outcomes. Students' cognitive outcomes are measured by means of a research skills test consisting of short multiple choice and short answer items (in order to assess research skills in a broad way), and a research skills task in which students are asked to integrate their skills in writing a research proposal (in order to assess research skills in an integrative manner). Students' motivational outcomes are measured by means of students' autonomous and controlled motivation, and students' amotivation. A pretest-intervention-posttest design was set up in order to compare 233 upper secondary school behavioral sciences students' outcomes among (1) a 4C/ID based online learning environment condition, and (2) an identical condition additively providing support for students' need satisfaction. Both learning environments proved equally effective in improving students' scores on the research skills test. Students in the need supportive condition scored higher on the research skills task compared to their peers in the baseline condition. Students' autonomous and controlled motivation were not affected by the intervention. Although, unexpectedly, students' amotivation increased in both conditions, students' amotivation was lower in the need supportive condition compared to students in the baseline condition. Theoretical relationships were established between students' need satisfaction, students' motivation (autonomous, controlled, and amotivation), and students' cognitive outcomes. These findings are discussed taking into account the COVID-19 affected setting in which the study took place.

**Keywords:** research skills, motivation, 4C/ID, self-determination theory, autonomy support, relatedness support, competence support

**Introduction**

Several scholars have argued that the process of learning research skills is often obstructed by motivational problems (Lehti & Lehtinen, 2005; Murtonen, 2005). Some even describe these issues as students having an aversion towards research (Pietersen, 2002). Examples of motivational problems are that students experience research courses as boring, inaccessible, or irrelevant to their daily lives (Braguglia & Jackson, 2012). In a research synthesis on teaching and learning research methods, Earley (2014) argues that students fail to see the relevance of research methods courses, are anxious or nervous about the course, are uninterested and unmotivated to learn the material, and have poor attitudes towards learning research skills. It should be mentioned that the studies mentioned above focused on the field of higher university education. In upper secondary education, to date, students' motivation towards learning research skills has rarely been studied. As difficulties while learning research seem to relate to problems involving students' previous experiences regarding learning research skills (Murtonen, 2005), we argue that fostering students' motivation from secondary education onwards is a promising area of research.

The current study combines insights from instructional design theory and self-determination theory (SDT, Deci & Ryan, 2000), in order to investigate the cognitive and motivational effects of providing psychological need support (support for the need for autonomy, competence and relatedness) in a 4C/ID based (van Merriënboer & Kirschner, 2018) online learning environment fostering upper secondary schools students' research skills. In the following section, we elaborate on the definition of research skills in the understudied domain of behavioral sciences; on 4C/ID (van Merriënboer & Kirschner, 2018) as an instructional design model for complex learning; and on self-determination theory and its related need theory (Deci & Ryan, 2000). In addition, the research questions addressed in the current study are outlined.

**Conceptual framework**

**Research skills**

As described by Fischer and colleagues (2014, p. 29), we define research skills[1] as a broad set of skills used "to understand how scientific knowledge is generated in different scientific disciplines, to evaluate the validity of science-related claims, to assess the relevance of new scientific concepts, methods, and findings, and to generate new knowledge using these concepts and methods". Furthermore, eight scientific activities learners engage in while performing research are distinguished, namely: (1) problem identification, (2) questioning, (3) hypothesis generation, (4) construction and redesign of artefacts, (5) evidence generation, (6) evidence evaluation, (7) drawing conclusions, and (8) communicating and scrutinizing (Fischer et al., 2014). Fischer and colleagues (2014) argue that both the nature of, and the weights attributed to each of these activities differ, between domains. Intervention studies aiming to foster research skills are almost

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[1] Fischer and colleagues (2014) refer to these research skills as scientific reasoning skills.

exclusively situated in natural sciences domains (Engelmann et al., 2016), leaving behavioral sciences domains largely understudied. The current study focuses on research skills in the understudied domain of behavioral sciences. We refer to the domain of behavioral sciences as the study of questions related to how people behave, and why they do so. Human behavior is understood in its broadest sense, and is the study of object in fields of psychology, educational sciences, cultural and social sciences.

**4C/ID**

The design of the learning environments used in this study is based on an existing instructional design model, namely the 4C/ID model (van Merriënboer & Kirschner, 2018). The 4C/ID model has been proven repeatedly effective in fostering complex skills (Costa et al., 2021), and thus drew our attention for the case of research skills, as research skills can be considered complex skills (it requires learners to integrate knowledge, skills and attitudes while performing complex learning tasks). Since the 4C/ID model focusses on supporting students' cognitive outcomes, it might not be considered as relevant from a motivational point of view. However, since we argue that a deliberately designed learning environment from a cognitive point of view is an important prerequisite to provide qualitative motivational support, we briefly sketch the 4C/ID model and its characteristics. The 4C/ID model has a comprehensive character, integrating insights from different theories and models (Merrill, 2002), and highlights the relevance of four crucial components: learning tasks, supportive information, part task-practice, and just-in-time information. Central characteristics of these four components are that a) high variability in authentic learning tasks is needed in order to deal with the complexity of the task; b) supportive information is provided to the students in order to help them build mental models and strategies for solving the task under study (Cook & McDonald, 2008); c) part-task practice is provided for recurrent skills that need to be automated; and d) just-in-time (procedural) information is provided for recurrent skills.

Taking into account students' cognitive struggles regarding research skills, and the existing research on the role of support in fostering research skills (see for example de Jong & van Joolingen, 1998), the 4C/ID model was found suitable to design a learning environment for research skills. This is partly because of its inclusion of (almost) all of the support found effective in the literature on research skills, such as providing direct access to domain information at the appropriate moment, providing learners with assignments, including model progression, the importance of students' involvement in authentic activities, and so on (Chi, 2009; de Jong & van Joolingen, 1998; de Jong, 2006; Engelmann et al., 2016;. While mainly implemented in vocational oriented programs, the 4C/ID model has been proposed as a good model to design learning environments aiming to foster research skills as well (Bastiaens et al., 2017; Maddens, Depaepe, Raes, & Elen, 2020b). Indeed, acquiring research skills requires complex learning processes (such as coordinating different constituent skills). Overall, the 4C/ID model can be considered to be highly suitable for designing learning environments aiming to foster research skills. Given its holistic design approach, it

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helps "to deal with complexity without losing sight of the interrelationships between the elements taught" (van Merriënboer & Kirschner, 2018, p. 5).

Although the 4C/ID model has been used widely to construct learning environments enhancing students' cognitive outcomes (see for example Fischer, 2018), research focusing on students' motivational outcomes related to the 4C/ID model is scarce (van Merriënboer & Kirschner, 2018). Van Merriënboer and Kirschner (2018) suggest self-determination theory (SDT; Deci & Ryan, 2000) and its related need theory as a sound theoretical framework to investigate motivation in relation to 4C/ID.

**Self-determination theory**

Self-determination theory (SDT; Deci & Ryan, 2000) provides a broad framework for the study of motivation and distinguishes three types of motivation: amotivation (a lacking ability to self-regulate with respect to a behaviour), extrinsic motivation (extrinsically motivated behaviours, be they self-determined versus controlled), and intrinsic motivation (the 'highest form' of self-determined behaviour) (Deci & Ryan, 2000). According to Deci and Ryan (2000, p. 237), intrinsic motivation can be considered "a standard against which the qualities of an extrinsically motivated behavior can be compared to determine its degree of self-determination". Moreover, the authors (Deci & Ryan, 2000, p. 237) argue that "extrinsic motivation does not typically become intrinsic motivation". As the current study focuses on research skills in an academic context in which students did not *voluntary* chose to learn research skills, and thus learning research skills can be considered *instrumental* (directed to attaining a goal), the current study focuses on students' amotivation, and students' extrinsic motivation, realistically striving for the most self-determined types of extrinsic motivation.

Four types of extrinsic motivation are distinguished by SDT (external regulation, introjection, identification, and integration). These types can be categorized in two overarching types of motivation (autonomous and controlled motivation). Autonomous motivation contains the integrated and identified regulation towards a task (be it because the task is considered interesting, or because the task is considered personally relevant respectively). Controlled motivation refers to the external and introjected regulation towards the task (as a consequence of external or internal pressure respectively) (Vansteenkiste et al., 2009). More autonomous types of motivation have been found to be related to more positive cognitive and motivational outcomes (Deci & Ryan, 2000).

SDT further maintains that one should consider three innate psychological needs related to students' motivation. These needs are the need for autonomy, the need for competence, and the need for relatedness. The need for autonomy can be described as the need to experience activities as being "concordant with one's integrated sense of self" (Deci & Ryan, 2000, p. 231). The need for competence refers to the need to feel effective when dealing with the environment (Deci & Ryan, 2000). The need for relatedness contains the

need to have close relationships with others, including peers and teachers (Deci & Ryan, 2000). The satisfaction of these needs is hypothesized to be related to more internalization, and thus to more autonomous types of motivation (Deci & Ryan, 2000). This relationship has been studied frequently (for a recent overview, see Vansteenkiste et al., 2020). Indeed, research established the positive relationships between perceived autonomy (see for example Deci et al., 1994), perceived competence (see for example Vallerand & Reid, 1984), and perceived relatedness (see for example Ryan & Grolnick, 1986 for a self-report based study) with students' more positive motivational outcomes. Apart from students' need satisfaction, several scholars also aim to investigate need frustration as a different notion, as "it involves an active threat of the psychological needs (rather than a mere absence of need satisfaction)" (Vansteenkiste et al., 2020, p. 9). In what follows, possible operationalizations are defined for the three needs.

Possible operationalizations of autonomy need support found in the literature are: teachers accepting irritation or negative feelings related to aspects of a task perceived as "uninteresting" (Reeve & Jang, 2006; Reeve et al., 2002; Reeve, 2006); providing a meaningful rationale in order to explain the value/usefulness of a certain task and stressing why involving in the task is important or why a rule exists (Deci & Ryan, 2000); using autonomy-supportive, inviting language (Deci et al., 1996); and allowing learners to regulate their own learning and to work at their own pace (Martin et al., 2018). Related to competence support, possible operationalizations are: providing a clear task rationale and providing structure (Vansteenkiste et al., 2012; Reeve, 2006); providing informational positive feedback after a learning activity (Deci et al., 1996; Martin et al., 2018; Vansteenkiste et al., 2012); providing an indication of progress and dividing content into manageable blocks (Martin et al., 2018; Schunk, 2003); and evaluating performance by means of previously introduced criteria (Ringeisen & Bürgermeister, 2015). Possible operationalizations concerning relatedness support are: teacher's relational supports (Ringeisen & Bürgermeister, 2015); encouraging interaction between course participants and providing opportunities for learners to connect with each other (van Merriënboer & Kirschner, 2018; Butz & Stupnisky, 2017); using a warm and friendly approach or welcoming learners personally into a course (Martin et al., 2018); and offering a platform for learners to share ideas and to connect (Butz & Stupnisky, 2017; Martin et al., 2018).

In the current research, SDT is selected as a theoretical framework to investigate students' motivation towards learning research skills, as, in contrast to other more purely goal-directed theories, it includes the concept of innate psychological needs or the Basic Psychological Need Theory (Deci & Ryan, 2000; Ryan, 1995; Vansteenkiste et al., 2020), and it describes the relation between these perceived needs and students' autonomous motivation: higher levels of perceived needs relate to more autonomous forms of motivation. The inclusion of this need theory is considered an advantage in the case of research skills because research revealed problems of students with respect to both their feelings of competence in relation

to research skills (Murtonen, 2005), as their feelings of autonomy in relation to research skills (Martin et al., 2018), as was indicated in the introduction. As such, fostering students' psychological needs while learning research skills seems a promising way of fostering students' motivation towards learning research skills.

**4C/ID and SDT**

One study (Bastiaens & Martens, 2007) was found to implement need support in 4C/ID based learning environments, comparing a traditional module, a 4C/ID based module and an autonomy supportive 4C/ID based module in a vocational undergraduate education context. Autonomy support was operationalized by means of providing choice to the learners. No main effect of the conditions was found on students' motivation. Surprisingly, providing autonomy support did also not lead to an increase in students' autonomy satisfaction. Similarly, no effects were found on students' relatedness and competence satisfaction. Remarkably, students did qualitatively report positive experiences towards the need support, but this did not reflect in their quantitatively reported need experiences. In a previous study performed in the current research trajectory, Maddens, Depaepe, Raes, & Elen (under review) investigated the motivational effects of providing autonomy support in a 4C/ID based online learning environment fostering students' research skills, compared to a learning environment not providing such support. Autonomy support was operationalized as stressing task meaningfulness to the students. Based on insights from self-determination theory, it was hypothesized that students in the autonomy condition would show more positive motivational outcomes compared to students in the baseline condition. However, results showed that students' motivational outcomes appeared to be unaffected by the autonomy support. One possible explanation for this unexpected finding was that optimal circumstances for positive motivational outcomes are those that allow satisfaction of autonomy, competence, ánd relatedness support (Deci & Ryan, 2000; Niemiec & Ryan, 2009), and thus, that the intervention was insufficiently powerful for effects to occur. Autonomy support has often been manipulated in experimental research (Deci et al., 1994; Reeve et al., 2004; Sheldon & Filak, 2008). However, the three needs are rarely simultaneously manipulated (Sheldon & Filak, 2008).

**Integrated need support**

Although not making use of 4C/ID based learning environments, some scholars have focused on the impact of integrated (autonomy, competence and relatedness) need support on learners' motivation. For example, Raes and Schellens (2015) found differential effects of a need supportive inquiry environment on upper secondary school students' motivation: positive effects on autonomous motivation were only found in students in a general track, and not in students in a science track. This indicates that motivational effects of need-supportive environments might differ between tracks and disciplines. However, Raes and Schellens (2015) did not experimentally manipulate need support, as the learning environment was assumed to be need-supportive and was not compared to a non-need supportive learning environment. Pioneers in

manipulating competence, relatedness and autonomy support in one study are Sheldon and Filak (2008), predicting need satisfaction and motivation based on a game-learning experience with introductory psychology students. Relatedness support (mainly operationalized by emphasizing interest in participants' experiences in a caring way) had a significant effect on intrinsic motivation. Competence support (mainly operationalized by means of explicating positive expectations) had a marginal significant effect on intrinsic motivation. No main effects on intrinsic motivation were found regarding autonomy support (mainly operationalized by means of emphasizing choice, self-direction and participants' perspective upon the task). However, as is often the case in motivational research based on SDT, the task at hand was quite straight forward (a timed task in which students try to form as many words as possible from a 4 x 4 letter grid), and thus, the applicability of the findings for providing need support in 4C/ID based learning environments for complex learning might be limited.

### This study

In the preceding section, several operationalizations of need support were discussed. Deci and Ryan (2000) argue that optimal circumstances for positive motivational outcomes are those that allow satisfaction of autonomy, competence, ánd relatedness support. However, such integrated need support has rarely been empirically studied (Sheldon & Filak, 2010). In addition, research investigating how need support can be implemented in learning environments based on the 4C/ID model is particularly scarce (van Merriënboer & Kirschner, 2018). This study aims to combine insights from instructional design theory for complex learning (van Merriënboer & Kirschner, 2018) and self-determination theory (Deci & Ryan, 2000) in order to investigate the motivational effects of providing need support in a 4C/ID based learning environment for students' research skills. A pretest-intervention-posttest design is set up in order to compare 233 upper secondary school behavioral sciences students' cognitive and motivational outcomes among two conditions: (1) a 4C/ID based online learning environment condition, and (2) an identical condition additively providing support for students' need satisfaction. The following research questions are answered based on a combination of quantitative and qualitative data (see 'method'): *(1) Does a deliberately designed (4C/ID-based) learning environment improve students' research skills, as measured by a research skills test and a research skills task?*; *(2) What is the effect of providing autonomy, competence and relatedness support in a deliberately designed (4C/ID-based) learning environment fostering students' research skills, on students' motivational outcomes (i.e. students' amotivation, autonomous motivation, controlled motivation, students' perceived value/usefulness, and students' perceived needs of competence, relatedness and autonomy)?*; *(3) What are the relationships between students' need satisfaction, students' need frustration, students' autonomous and controlled motivation and students' cognitive outcomes (research skills test and research skills task)?*; *(4) How do students experience need satisfaction and need frustration in a deliberately designed (4C/ID-based) learning environment?*.

The first three questions are answered by means of quantitative data. Since the learning environment is constructed in line with existing instructional design principles for complex learning, we hypothesize that both learning environments will succeed in improving students' research skills (RQ1). Relying on insights from self-determination theory (Deci & Ryan, 2000), we hypothesize that providing need support will enhance students' autonomous motivation (RQ2). In addition, we hypothesize students' need satisfaction to be positively related to students' autonomous motivation (RQ3). These hypotheses on the relationship between students' needs and students' motivation rely on Vallerands' (1997) finding that changes in motivation can be largely explained by students' perceived competence, autonomy and relatedness (as psychological mediators). More specifically, Vallerand (1997) argues that environmental factors (in this case the characteristics of a learning environment) influence students' perceptions of competence, autonomy, and relatedness, which, in turn, influence students' motivation and other affective outcomes. In addition, based on the self-determination literature (Deci & Ryan, 2000), we expect students' motivation to be positively related to students' cognitive outcomes. In order to answer the fourth research question, qualitative data (students' qualitative feedback on the learning environments) is analysed and categorized based on the need satisfaction and need frustration concepts (RQ4) in order to thoroughly capture the meaning of the quantitative results collected in light of RQ1-3. No hypotheses are formulated in this respect.

**Methodology**

*Participants*

The study took place in authentic classroom settings in upper secondary behavioral sciences classes. In total, 233 students from 12 classes from eight schools in Flanders participated in the study. All participants are 11th or 12th grade students in a behavioral sciences track[2] in general upper secondary education in Flanders (Belgium). Classes were randomly assigned to one out of two experimental conditions. Of all 233 students, 105 students (with a mean age of 16.32, *SD* .90) worked in the baseline condition (of which 62% 11th grade students, 36% 12th grade students, and 2% not determined; and of which 31% male, 68% female, and 1% 'other'), and 128 students (with a mean age of 16.02, *SD* .59) worked in the need supportive condition (of which 80% 11th grade students, and 20% 12th grade students; and of which 19% male, and 81% female). As the current study did not randomly assign students *within* classes to one out of the two conditions, this study should be considered quasi-experimental. Full randomization was considered but was not feasible as students worked in the learning environments in class, and would potentially notice the experimental differences when observing their peers working in the learning environment. As such, we argued that this

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[2] In Flanders, during the time of study, four different types of education are offered from the second stage of secondary education onwards (EACEA, 2018) (general secondary education, technical secondary education, secondary education in the arts and vocational secondary education). Behavioral sciences is a track in general secondary education.

would potentially cause bias in the study. By taking into account students' pretest scores on the relevant variables (cognitive and motivational outcomes) as covariates, we aimed to adjust for inter-conditional differences.No such differences were found for students' autonomous motivation $t(226) = -.115$, $p < .909$, $d = .015$, and students' amotivation $t(226) = -.658$, $p < .511$, $d = -.088$. However, differences were observed for students' controlled motivation $t(226) = -2.385$, $p < .018$, $d = -.318$, and students' scores on the LRST pretest $t(225) = -5.200$, $p < .001$, $d = -.695$.

*Study design and procedure*

In a pretest session of maximum two lesson hours, the Leuven Research Skills Test (LRST, Maddens, Depaepe, Janssen, Raes, & Elen, 2020a), the Academic Self-Regulation Scale (ASRS, Vansteenkiste et al., 2009), and four items related to students' amotivation (Aydin et al., 2014) were administered in class via an online questionnaire, under supervision of the teacher. In the subsequent eight weeks, participants worked in the online learning environment, one hour a week. Out of the 233 participating students, 105 students studied in a baseline online learning environment. The baseline online learning environment[3] is systematically designed using existing instructional design principles for complex learning based on the 4C/ID model (van Merriënboer & Kirschner, 2018). All four components of the 4C/ID model were taken into account in the design process: regarding the first component, the learning tasks included real-life, authentic cases. More specifically, tasks were selected from the domains of psychology, educational sciences and sociology. As such, there was a large variety in the cases used in the learning tasks. This large variety in learning tasks is expected to facilitate transfer of learners' research skills in a wide range of contexts. Furthermore, the tasks were ill-structured and required learners to make judgments, in order to provoke deep learning processes. Regarding the second component, supportive information was provided for complex tasks in the learning environment, such as formulating a research question, where students can consult general information on what constitutes a good research question, can consult examples or demonstrations of this general information, and can receive cognitive feedback on their answers (for example by means of example answers). Examples of the implementation of the third component (procedural information) are the provision of information on how to recognize a dependent and an independent variable by means of on-demand (just-in-time) presentation by means of pop-ups; information on how to use Boolean operators; and information on how to read a graph. To avoid split attention, this kind of information was integrated with the task environment itself (van Merriënboer & Kirschner, 2018). Finally, the fourth component, part-task-practice (by means of short tests) was implemented for routine aspects of research skills that should be automated, for example the formulation of a search query.

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[3] For a complete overview on the design and the evaluation of this learning environment, see Maddens et al (2020b).

The remaining participating students ($n = 128$) completed an adapted version of the baseline online learning environment, in which autonomy, relatedness and competence support are provided. In total, need support consisted of 12 implementations (four implementations for each need), based on existing research on need support. An overview of these adaptations can be found in Table 1. Although, ideally, students would work in class, under supervision of their teacher, this was not possible for all classes, due to the COVID-19 restrictions[4]. As a consequence, some students completed the learning environment partly at home. All students were supervised by their teachers (be it virtually or in class), and the researcher kept track of students' overall activities in order to be able to contact students who did not complete the main activities. During the last two sessions of the intervention, participants submitted a two-pages long research proposal ("two-pager"). One week after the intervention, the LRST (Maddens et al., 2020a), the ASRS (Vansteenkiste et al., 2009), four items related to students' amotivation (Aydin et al., 2014), the value/usefulness scale (Ryan 1982) and the Basic Psychological Need Satisfaction and Frustration Scale (BPNSNF, Chen et al., 2015) were administered in a posttest session of maximum two hours. Although most classes succeeded in organizing this posttest session in class, for some classes this posttest was administered at home. However, all classes were supervised by the teacher (be it virtually or in class). These contextual differences at the test moments will be reflected upon in the discussion section.
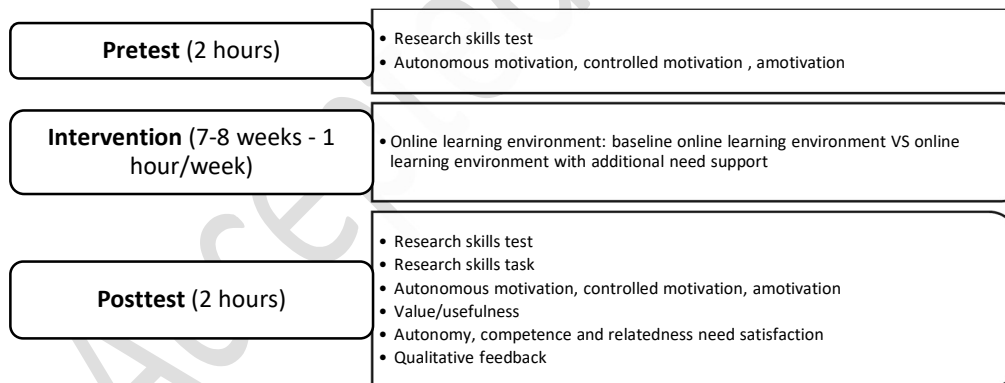
**Figure 1**

*Study overview*



**Table 1.**

*Adaptations online learning environment*

| Support type | Implementations | Concrete operationalizations in the need supportive learning environment |
|---|---|---|
| Autonomy support | A1. Providing meaningful rationales in order to explain the value/usefulness of a certain task | - A1a. Video of a peer (student) stressing value/usefulness of learning environment before starting the learning environment. |

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[4] During the time of study, the COVID-19 restrictions became more strict: students in upper secondary education could only come to school half of the time. Therefore, some students completed the last modules of the learning environment at home.

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|---|---|---|
| | and stressing why involving in the task is important or why a rule exists (Assor et al., 2002; Deci et al., 1994; Deci & Ryan, 2000; Steingut et al., 2017) | - A1b. Teacher stressing importance learning environment before starting the learning environment<br>- A1c. Avatars stressing importance (see Author et al., under review); for example an avatar mentioning 'After having completed this module, I know how to formulate a research question for example when I am writing a bachelor thesis in my future academic career".<br>- A1d. 2-pager: adding examples of subjects of peers, in order for the task to feel more familiar |
| | A2. Accepting irritation/acknowledging negative feelings (acknowledgment of aspects of a task perceived as uninteresting) (Reeve et al., 2002; Reeve & Jang, 2006) | - A2a. Including statements during tasks: "We understand that this might cost an effort, but previous studies proved that students can learn from performing this activity…"<br>- A2b. At the end of each module: teacher asks about students' difficulties |
| | A3. Using autonomy-supportive, inviting language (Deci et al., 1996) | - A3a. Personal task rationale, for example: "I am curious about how you would tackle this problem.", systematically implemented in the assignments |
| | A4. Allowing learners to regulate their own learning and to work at their own pace. The use of a non-pressured environment (Martin et al., 2018) | - A4a. Adding a statement after each task class: "no need to compare your progress to that of your peers, you can work at your own pace!" |
| Relatedness support | R1. Teacher's relational supports (Ringeisen & Bürgermeister, 2015) | - R1a. Before starting the learning environment: stressing that students can contact researcher and teacher<br>- R1b. Researcher (scientist-mentor) sends motivational messages to the group (on a weekly basis) |
| | R2. Encouraging interaction between course participants; providing opportunities for learners to connect with each other; introducing learning tasks that require group work or learning networks (Butz & Stupnisky, 2017; van Merriënboer & Kirschner, 2018) | - R2a. Opening every task class: reminding students they can contact the researcher with questions<br>- R2b. Every task class: one opportunity to share answers in the forum |
| | R3. Using a warm and friendly approach, welcoming learners personally into a course (Martin et al., 2018) | - R3a. Personal welcoming message in the beginning of the online learning environment |
| | R4. Offering a platform for learners to share ideas and to connect (Butz & Stupnisky, 2017; Martin et al., 2018) | - R4a. Asking students to post an introduction post in the forum to sum up their expectations of the course (once, in the beginning of the learning environment) |
| Competence support | C1. Clear task rationale, providing structure (Reeve, 2006; Vansteenkiste et al., 2012) | - Introductory video of researcher explaining what students will learn in the online learning environment |
| | C2. Informational positive feedback after learning activity (Deci et al., 1996; Martin et al., 2018; Vansteenkiste et al., 2012) | - Personal short feedback after every task class, formulated in a positive manner<br>- Adding motivational quotes to example answers: "Thank you for submitting your answer! You will receive feedback at the end of this module, but until then, you can compare your answer to the example answer". |
| | C3. Indication of progress; dividing content into manageable blocks (Martin et al., 2018) | - After every task class: ask students to mark their progress |

| | C4. Evaluating performance by means of previously introduced criteria (Ringeisen & Bürgermeister, 2015) | - SAP-chart referring to instructions 2-pager task<br>- Short guide 2-pager task |
|---|---|---|

*Instruments*

In this section, we elaborate on the tests used during the pretest and the posttest. Example items for each scale are presented in Appendix 1. An overview of the instruments can be found in Table 2.

Motivational outcomes

In the current study, two groups of motivational outcomes are assessed: (1) students' need satisfaction and frustration, and students' experiences of value/usefulness; and (2) students' level of autonomous motivation, controlled motivation, and amotivation. When administered at both pretest and posttest level (see 'procedure'), the internal consistency values are reported respectively.

The BPNSNF-training scale (The Basic Psychological Need Satisfaction and Frustration Scale, Chen et al., 2015; translated version Aelterman et al., 2016[5]) measured students' need satisfaction and need frustration while working in the learning environment, and consists of 24 items (four items per scale): (autonomy satisfaction, $\alpha$ = .67; $\omega$ = .67; autonomy frustration, $\alpha$ = .76; $\omega$ = .76; relatedness satisfaction, $\alpha$ = .79; $\omega$ = .79; relatedness frustration, $\alpha$ = .60; $\omega$ = .61; competence satisfaction, $\alpha$ = .72; $\omega$ = .73; competence frustration, $\alpha$ = .68; $\omega$ = .67). The items are Likert-type items ranging from one (not at all true) to five (entirely true). Although the current study focusses mainly on students' need satisfaction, the scales regarding students' need frustration are included in order to be able to also detect students' potential ill-being and in order to detect potential critical issues regarding students' needs. In addition to the BPNSNF, by means of seven Likert-type items ranging from one (not at all true) to seven (entirely true), the (for the purpose of this research translated) value/usefulness scale of the Intrinsic Motivation Inventory (IMI, Ryan, 1982) measured to what extent students valued the activities of the online learning environment ($\alpha$ = .92; $\omega$ = .92). Since in the research skills literature problems have been observed related to students' perceived value/usefulness of research skills (Earley, 2015; Murtonen, 2005), and this concept is not sufficiently stressed in the BPNSNF-scale, we found it useful to include this value/usefulness scale to the study. The difference in the range of the answer possibilities (one to five versus one to seven) exists because we wanted to keep the range as initially prescribed by the authors of each instrument. All motivational measures are calculated by adding the scores on every item, and dividing this sum score by the number of items on a

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[5] The BPNSNF-training scale is initially constructed to evaluate motivation related to workshops. The phrasing was adjusted slightly in order for the suitability for the current study. For example, we changed the wording 'during the past workshop…' to 'while completing the online learning environment…'.

scale, leading to continuous outcomes. Although the IMI and the BPNSNF targeted students' experiences *while* completing the online learning environment, these measures were administered during the posttest. Thus, students had to think retrospectively about their experiences. In order to prevent cognitive overload while completing the online learning environment, these measures were not administered during the intervention itself.

Students' autonomous and controlled motivation towards learning research skills was measured by means of the Dutch version of the Academic Self-Regulation Scale (ASRS; Vansteenkiste et al., 2009), adapted to 'research skills'. The ASRS consists of Likert-type items ranging from one (do not agree at all) to five (totally agree), and contains eight items per subscale (autonomous and controlled motivation). In the autonomous motivation scale, four items are related to identified regulation, and four items are related to intrinsic motivation[6]. In the controlled motivation scale, four items are related to external regulation, and four items are related to introjected regulation. Both scales (autonomous motivation and controlled motivation) indicated good internal consistency for the study's data (autonomous motivation: $\alpha = .91$; .92; $\omega = .90$; .92; controlled motivation: $\alpha = .83$; .86; $\omega = .82$; .85). The items were adapted to the domain under study (motivation to learn about research skills). Based on students' motivational issues related to research skills, we found it useful to also include a scale to assess students' amotivation. This was measured with (for the purpose of the current research translated) four items related to students' amotivation regarding learning research skills, adapted from Academic Motivation Scale for Learning Biology (Aydin et al., 2014) ($\alpha = .80$; .75; $\omega = .81$; .75). Also this measure consist of Likert-type items ranging from one (do not agree at all) to five (totally agree).

Cognitive outcomes

Students' research skills proficiency was measured by means of a research skills test (Maddens et al., 2020a) and a research skills task.

The research skills test used in this study is the LRST (Maddens et al., 2020a) consisting of a combination of 37 open ended and close ended items ($\alpha = .79$; .82; $\omega = .78$; $\omega = .80$ for this data set), administered via an online questionnaire. Each item of the LRST is related to one of the eight epistemic

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[6] In the current study, we would label the items categorized as 'intrinsic motivation' in ASRS (finding something interesting, fun, fascinating or a pleasant activity) as 'integration'. In SDT (Deci & Ryan, 2000, Deci et al., 2017), integration is described as being "fully volitional", or "wholeheartedly engaged", and it is argued that fully internalized extrinsic motivation does not typically become intrinsic motivation, but rather remains extrinsic even though fully volitional (because it is still instrumental). In the context of the current study, in which students learn about research skills because this is instructed (thus, out of instrumental motivations), we think that the term integration is more applicable than pure intrinsic motivation in self-initiated contexts (which can be observed for example in children's play or in sports).

activities regarding research skills as mentioned in the introduction (Fischer et al., 2014), and is scored as 0 or 1. The total score on the LRST is calculated by adding the mean subscale scores (related to the eight epistemic activities), and dividing them by eight (the number of scales). In a previous study (Maddens et al., 2020a), the LRST was checked and found suitable in light of interrater reliability ($\kappa$ = .89). As the same researchers assessed the same test with a similar cohort in the current study, the interrater reliability was not calculated for this study.

In the research skills task ("two pager task"), students were asked to write a research proposal of maximum two pages long. The concrete instructions for this research proposal are given in Appendix 1. In this research proposal, students were asked to formulate a research question and its relevance; to explain how they would tackle this research question (method and participants); to explain their hypotheses or expectations; and to explain how they would communicate their results. The two-pager task was analyzed using a pairwise comparison technique, in which four evaluators (i.e. the four authors of this paper) made comparative judgements by comparing two two-pagers at a time, and indicating which two-pager they think is best. All four evaluators are researchers in educational sciences and are familiar with the research project and with assessing students' texts. This shared understanding and expertise is a prerequisite for obtaining reliable results (Lesterhuis, 2018). The comparison technique is performed by means of the Comproved tool (https://comproved.com). As described by Lesterhuis (2018, p. 18), "the comparative judgement method involves assessing a text on its overall quality. However, instead of requiring an assessor to assign an absolute score to a single text, comparative judgement simplifies the process to a decision about which of two texts is better". In total, 1635 comparisons were made (each evaluator made 545 comparisons), and this led to a (interrater)reliability score of .79. In a next step, these comparative judgements were used to rank the 218 products (15 students did not submit a two-pager) on their quality; and the products were graded based on their ranking. This method was used to grade the two-pagers because it facilitates the holistic evaluation of the tasks, based on the judgement of multiple experts (interrater reliability).

**Table 2**

*Overview instruments*

| Measured construct(s) | Instrument | Format | Number of items | Internal consistency reliability/interrater reliability | When administered? |
|---|---|---|---|---|---|
| Psychological need frustration and satisfaction | BPNSNF-training scale (Chen et al., 2015 ; translated version Aelterman et al., 2016) | Likert-type items, 5 point scale | 24 items (4 items per scale) | autonomy satisfaction, $\alpha$ = .67; $\omega$ = .67; autonomy frustration, $\alpha$ = .76; $\omega$ = .76; relatedness satisfaction, $\alpha$ = .79; $\omega$ = .79; relatedness frustration, $\alpha$ = .60; $\omega$ = .61; competence satisfaction, $\alpha$ | Post |

| | | | | = .72; ω = .73; competence frustration, $\alpha$ = .68; ω = .67 | |
|---|---|---|---|---|---|
| Experienced value/usefulness of the learning environment | Intrinsic Motivation Inventory (Ryan, 1982) | Likert-type items, 7-point scale | 7 items | $\alpha$ = .92; ω = .92 | Post |
| Autonomous and controlled motivation | ASRS (Vansteenkiste et al., 2009) | Likert-type items, 5 point scale | 16 items (8 items for autonomous motivation, 8 items for controlled motivation | Autonomous motivation: $\alpha$ = .91; .92; ω = .90; .92[1]<br><br>Controlled motivation: $\alpha$ = .83; .86; ω = .82; .85 | Pre, post |
| Amotivation | Academic Motivation Scale for Learning Biology (adapted for the context) (Aydin et al., 2014) | Liker-type items, 5 point scale | 4 items | $\alpha$ = .80; .75; ω = .81; .75 | Pre, post |
| Research skills test | LRST (Maddens et al., 2019) | Combination of open ended and close ended conceptual and procedural knowledge items, each scored as 0 or 1 | 37 items | $\alpha$ = .79; .82; ω = .78; ω = .80 | Pre, post |
| Research skills task | Two pager task (Author et al., under review) | Open ended question (performance assessment), assessed by means of a pairwise comparison technique | 1 task | Interreliability score = .79 | Post |

*1* When administered at both pretest and posttest level (see 'procedure'), the internal consistency values are reported respectively.

Qualitative feedback

Students' experiences with the online learning environment were investigated in the online learning environment itself. After completing the learning environment, students were asked how they experienced the tasks, the theory, the opportunity to post answers in the forum and to ask questions via the chat, what they liked or disliked in the online learning environment, and what they disliked in the online learning environment.

*Analysis*

The first research question ("*Does a deliberately designed (4C/ID-based) learning environment improve students' research skills, as measured by a research skills test and a research skills task?"*) is answered by means of a paired samples *t*-test in order to look for overall improvements in order to detect potential general trends, followed by a full factorial MANCOVA, as this allows us to investigate the effectiveness for both conditions taking into account students' pretest scores. Hence, the condition is included as an experimental factor, and students' scores on the LRST and the two-pager task are included as continuous outcome

variables. Students' pretest scores on the LRST are included as a covariate. Prior to the analysis, a MANCOVA model is defined taking into account possible interaction effects between the experimental factor and the covariate.

The second research question ("*What is the effect of providing autonomy, competence and relatedness support in a deliberately designed (4C/ID-based) learning environment fostering students' research skills, on students' motivational outcomes, i.e. students' amotivation, autonomous motivation, controlled motivation, students' perceived value/usefulness, and students' perceived needs of competence, relatedness and autonomy)?"*);) is answered by means of a full factorial MANCOVA. The condition (need satisfaction condition versus baseline condition) is included as an experimental factor, and students' responses on the value/usefulness, autonomous and controlled motivation, amotivation, and need satisfaction scales are included as continuous outcome variables. ASRS pretest scores (autonomous and controlled motivation) are included as covariates in order to test the differences between group means, adjusted for students' a priori motivation. Prior to the analysis, a MANCOVA model is defined taking into account possible interaction effects between the experimental factor and the covariates, and assumptions to be met to perform a MANCOVA are checked[7].

The third research question ( "*What are the relationships between students' need satisfaction, students' need frustration, students' autonomous and controlled motivation and students' cognitive outcomes (research skills test and research skills task)?*"), is initially answered by means of five multiple regression analyses. The first three regressions include the need satisfaction and frustration scales, and students' value/usefulness as independent variables, and students' (1) autonomous motivation, (2) controlled motivation, and (3) amotivation as dependent variables. The fourth and fifth regressions include students' autonomous motivation, controlled motivation, and amotivation as independent variables, and students' (4) LRST scores, and (5) scores on the two-pager task as dependent variables. As a follow-up analysis (see 'results') two additional regression analyses are performed to look into the direct relationships between students' perceived needs and students' experienced value/usefulness, with students' cognitive outcomes (LRST (6) and two-pager (7)). As the goal of this analysis is to investigate the relationships between variables as described in SDT research, this analysis focuses on the full sample, rather than distinguishing between the two conditions. An 'Enter' method (Field, 2013) is used in order to enter the independent variables simultaneously (in line with Sheldon et al., 2008).

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[7] Levene's test for homogeneity of variances was significant for the outcome "two-pager". However, we continued with the analyses since the treatment group sizes are roughly equal, and thus, the assumption of homogeneity of variances does not need to be considered (Field, 2013). Levene's test for homogeneity of variances was non-significant for all the other outcome measures.

The fourth research question ("*How do students experience need satisfaction and need frustration in a deliberately designed (4C/ID-based) learning environment?"*) is analyzed by means of the knowledge management tool Citavi. Based on the theoretical framework, students' experiences are labeled by the codes 'autonomy satisfaction, autonomy frustration, competence satisfaction, competence frustration, relatedness satisfaction, and relatedness frustration'. For example, students' quotes referring to the value/usefulness of the learning environment, are labeled as 'autonomy satisfaction' or 'autonomy frustration'. Students' references towards their feelings of mastery of the learning content are labeled as 'competence satisfaction' or 'competence frustration'. Students' quotes regarding their relationships with peers and teachers are labeled as 'relatedness satisfaction' or 'relatedness frustration'.

**Figure 2**

Overview variables
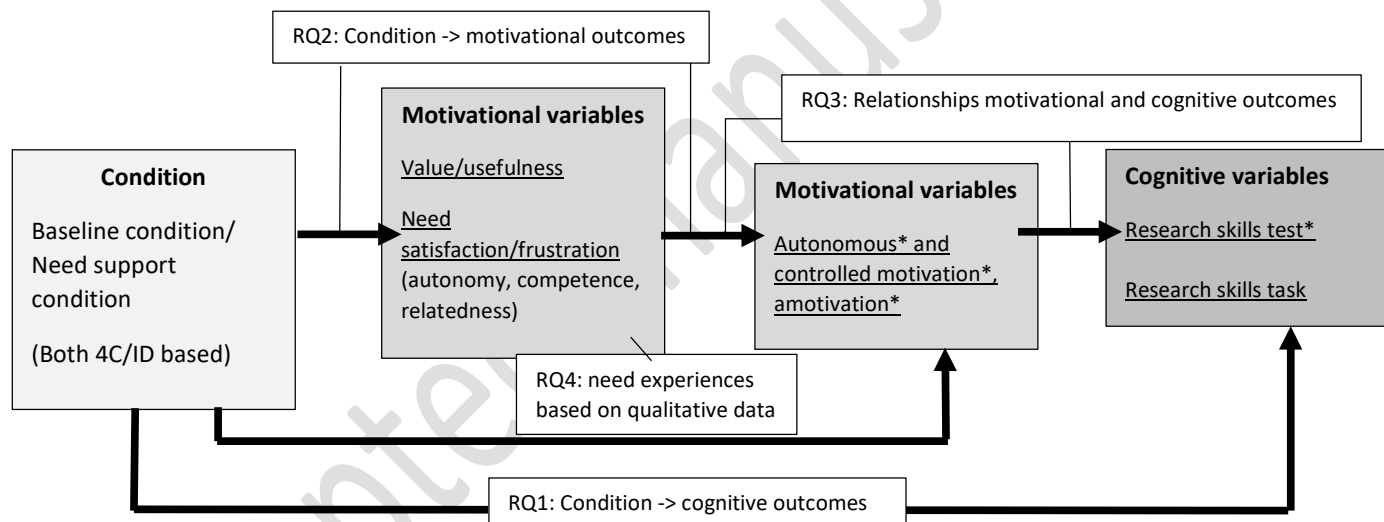


*For the variables autonomous motivation, controlled motivation, amotivation and research skills test, we control for a priori differences.

**Results**

*RQ1: Does the deliberately designed (4C/ID based) learning environments improve students' research skills, as measured by a research skills test and a research skills task?*

Paired samples *t*-test. A paired samples *t*-test reveals that, in general, students ($n = 210$) improved on the LRST-posttest ($M = .57$, $SD = .16$) compared to the pretest ($M = .51$, $SD = .15$) (range 0-1). The

difference  between the posttest and the pretest is significant $t(209)$ = -8.215, $p$ < .001, $d^8$ = -.567. The correlation between the LRST pretest and posttest is .70 ($p$ < .010).

MANCOVA. A MANCOVA model ($n$ = 196) was defined checking for possible interaction effects between the experimental factor and the covariate in order to control for the assumption of 'independence of the covariate and treatment effect' (Field, 2013). The covariate LRST pretest did not show significant interaction effects for the two outcome variables LRST post ($p$ = .259) and the twopager task ($p$ = .702). The correlation between the outcome variables (LRST post and two-pager), is .28 ($p$ < .050).

Of all 233 students, 36 students were excluded from the main analysis because of missing data (for example, because they were absent during a pretest or posttest moment). These students were excluded by means of a listwise deletion method because we found it important to use a complete dataset, since, in a lot of cases, students who did not complete the pretest or posttest, did also not complete the entire learning environment. Including partial data for these students could bias the results. The baseline condition counted 86 students, and the need satisfaction condition counted 111 students. Using Pillai's Trace ($V$ = .070, $F(2,193)$ = 7.285, $p$ = <.001), there was a significant effect of the condition on the cognitive outcome variables, taking into account students' LRST pretest scores. Separate univariate ANOVAs on the outcome variables revealed no significant effect of the condition on the LRST posttest measure, $F(1,194)$ = 2.45, $p$ = .120. However, a significant effect of condition was found on the two-pager scores, $F(1,194)$ = 13.69, $p$ < .001  (in the baseline group, the mean score was 6,6/20; in the need condition group, the mean score was 7,6/20). It should be mentioned that both scores are rather low.

*RQ2: What is the effect of providing autonomy, competence and relatedness support in a deliberately designed (4C/ID based) learning environment fostering students' research skills, on students' motivational outcomes (students' amotivation, autonomous motivation, controlled motivation, students' perceived value/usefulness, and students' perceived needs of competence, relatedness and autonomy)?*

Paired samples *t*-tests. The correlations between students' pretest and posttestscores for the motivational measures are .67 ($p$ < .010) for autonomous motivation; .44 ($p$ < .010) for controlled motivation, and .38 for amotivation ($p$ < .010). Regarding the differences in students' motivation, three unexpected findings were observed. Overall, students' ($n$ = 215) amotivation was higher on the posttest ($M$ = 2.26, $SD$ = .89) compared to the pretest ($M$ = 1.77, $SD$ = .79) (based on a score between 1 and 5). The difference  between the posttest and the pretest is significant $t(214)$ = -7,69, $p$ < .001, $d$ = -.524. Further analyses learn that the amotivation means in the baseline group increased with .65, and the amotivation in

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[8] Cohen's D is calculated in SPSS by means of the formula: $D = \frac{M1 - M2}{Sp}$

the need support group increased with .37. In addition, students' (*n* = 215) autonomous motivation was higher on the pretest (*M* = 2.81, *SD* = .81) compared to the posttest (*M* = 2.64, *SD* = .82). The difference between the posttest and the pretest is significant *t*(214) = 3.72, *p* < .001, *d* = .254. Students' mean scores on autonomous motivation in the baseline condition decreased with .19, and students' autonomous motivation in the need support condition decreased with .15. Students' (*n* = 215) controlled motivation was higher on the posttest (*M* = 2.33, *SD* = .75) compared to the pretest (*M* = 1.93, *SD*= .67). The difference between the posttest and the pretest is significant *t*(214) = -7.72, *p* < .001, *d* = -.527. Students' controlled motivation in the baseline group increased with .36, and students' controlled motivation in the need support group increased with .43. However, overall, all mean scores are and stay below neutral score (below 3), indicating robust low autonomous, controlled and amotivation scores (see Table 3). An independent samples *T*-test on the mean differences between these measures shows that the increases/decreases on autonomous motivation (*t*(213) = -.506, *p* = .613, *d* = -.069) and controlled motivation (*t*(213) = -.656, *p* = .513, *d* = -.090) did not differ between the two groups. However, the increases in amotivation (*t*(213) = 2.196, *p* = .029, *d* = .301) does differ significantly between the two conditions. More specifically, the increase was lower in the need supportive condition compared to the baseline condition.

**Table 3**

*Mean scores and standard deviations motivational variables*

| Variable | Range | Baseline condition *(M, SD)* | | Need supportive condition *(M, SD)* | |
|---|---|---|---|---|---|
| Value/usefulness | 1-7 | 5.12; .94 | | 5.14; 1.14 | |
| Autonomy satisfaction | 1-5 | 3.14; .62 | | 3.13; .62 | |
| Autonomy frustration | 1-5 | 2.94; .79 | | 3; .85 | |
| Competence satisfaction | 1-5 | 3.18; .62 | | 3.19; .58 | |
| Competence frustration | 1-5 | 2.77; .74 | | 2.74; .71 | |
| Relatedness satisfaction | 1-5 | 2.73; .80 | | 2.43; .82 | |
| Relatedness frustration | 1-5 | 1.91; .73 | | 2.43; .65 | |
| Autonomous motivation[a] | | **Pretest** | **Posttest** | **Pretest** | **Posttest** |
| | 1-5 | 2.83; .82 | 2.65; .87 | 2.81; .81 | 2.65; .77 |
| Controlled motivation[b] | | **Pretest** | **Posttest** | **Pretest** | **Posttest** |
| | 1-5 | 1.82; .66 | 2.19; .72 | 2.02; .66 | 2.45; .76 |

| Amotivation[c] | | Pretest | Posttest | Pretest | Posttest* |
|---|---|---|---|---|---|
| | 1-5 | 1.74; .72 | 2.38; .91 | 1.81; .86 | 2.18; .87 |

[a].Overall, students' ($n$ = 215) autonomous motivation was significantly higher on the pretest compared to the posttest ($t$(214) 3.72, $p$ <= .001, $d$ = .254. [b]. Students' (n = 215) controlled motivation was significantly higher on the posttest compared to the pretest ($t$(214) = -7.72, $p$ <= .001, $d$ = -.527. [c].Students' ($n$ = 215) amotivation was significantly higher on the posttest compared to the pretest ($t$(214) = -.7,69, $p$ <= .001, $d$ = -.534).

MANCOVA. Of all 233 students, 18 students were excluded from the analysis because of missing data (for example, because they were absent during a pretest or posttest moment). Compared to the cognitive analyses, the amount of missing data is lower concerning motivational outcomes since, concerning the cognitive outcomes, some students did not complete the two-pager task. However, we found it important to use all relevant data and chose to report this is in a clear way. In total, the baseline condition counted 97 students, and the experimental condition counted 118 students. Similar to the analysis for the cognitive outcomes, a MANCOVA model was defined to check for possible interaction effects between the experimental factor and the covariate in order to control for the assumption of 'independence of the covariate and treatment effect' (Field, 2013). The covariates did not show significant interaction effects for the outcome variables[9].

Using Pillai's Trace ($V$ = .113, $F$ (10,201) = 2.558, $p$ = .006), there was a significant effect of condition on the motivational variables, taking into account students' autonomous and controlled pretest scores, and students' a priori amotivation. Separate univariate ANOVAs on the outcome variables revealed a significant effect of the condition on the outcome variables amotivation, $F$(1,210) = 3.98, $p$ = .047; and relatedness satisfaction $F$(1,210) = 6.41, $p$ = .012. As was hypothesized, students in the need satisfaction group reported less amotivation ($M$ = 2.38), compared to students in the baseline group ($M$ = 2.18). In contrast to what was hypothesized, students in the need satisfaction group reported less relatedness satisfaction ($M$ = 2.43) compared to students in the baseline group ($M$ = 2.73), and no significant effects of condition were found on the outcome variables autonomous motivation post, controlled motivation post, value/usefulness, autonomy satisfaction, autonomy frustration, competence satisfaction, competence

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[9] Condition x amotivation pretest → Value/usefulness: $p$ = .826; → autonomous motivation: $p$ = .588; → controlled motivation: $p$ = .224; amotivation: $p$ = .790; autonomy satisfaction: $p$ = .553; autonomy frustration: $p$ = .594; competence satisfaction: $p$ = .064; competence frustration: $p$ = .459; relatedness satisfaction: $p$ = .336; relatedness frustration: $p$ = .352.

Condition x autonomous motivation pretest → Value/usefulness: $p$ = .251; → autonomous motivation: $p$ = .269; → controlled motivation: $p$ = .457; amotivation: $p$ = .219; autonomy satisfaction: $p$ = .794; autonomy frustration: $p$ = .096; competence satisfaction: $p$ = .682; competence frustration: $p$ = .699; relatedness satisfaction: $p$ = .943; relatedness frustration: $p$ = .870.

Condition x controlled motivation pretest → Value/usefulness: $p$ = .882; → autonomous motivation: $p$ = .270; → controlled motivation: $p$ = .782; amotivation: $p$ = .940; autonomy satisfaction: $p$ = .815; autonomy frustration: $p$ = .737; competence satisfaction: $p$ = .649; competence frustration: $p$ = .505; relatedness satisfaction: $p$ = .625; relatedness frustration: $p$ = .741

frustration, and relatedness frustration. Table 4 shows the correlations between the motivational outcome variables.

**Table 4**

*Correlations  motivational outcome variables*

|  | AM | CM | AMOT | VU | AS | AF | CS | CF | RS | RF |
|---|---|---|---|---|---|---|---|---|---|---|
| **AM** | 1 | | | | | | | | | |
| **CM** | -.03 | 1 | | | | | | | | |
| **AMOT** | -.21** | .41** | 1 | | | | | | | |
| **VU** | .66** | -.07 | -.36** | 1 | | | | | | |
| **AS** | .64** | -.16** | -.28** | .60** | 1 | | | | | |
| **AF** | -.40** | .40** | .35** | -.41** | -.58** | 1 | | | | |
| **CS** | .48** | -.19** | -.16* | .46** | .58** | -.41** | 1 | | | |
| **CF** | -.11 | .29** | .22** | -.11 | -.31** | .41** | -.52** | 1 | | |
| **RS** | .27** | -.03 | -.03 | .15* | .30** | -.33** | .29** | -.19** | 1 | |
| **RF** | -.03 | .19** | .11 | -.13 | -.10** | .21** | *.25** | .32** | -.28** | 1 |

** Correlation is significant at the 0.010 level (2-tailed).
* Correlation is significant at the 0.050 level (2-tailed)
Note. AM = autonomous motivation, CM = controlled motivation, AMOT = amotivation, VU = value/usefulness, AS = autonomy satisfaction, AF = autonomy frustration, CS = competence satisfaction, CF = competence frustration, RS = relatedness satisfaction, RF = relatedness frustration

*RQ3: What are the relationships between students' need satisfaction, students' need frustration, students' autonomous and controlled motivation and students' cognitive outcomes (research skills test and research skills task)?*

The third research question (investigating the relationships between students' need satisfaction, students' motivation and students' cognitive outcomes), is answered by means of five multiple regression analyses. The first three regressions include the need satisfaction and frustration scales, and students value/usefulness as independent variables, and students' (1) autonomous motivation, (2) controlled motivation, and (3) amotivation as dependent variables ($n = 219$). The fourth and fifth regressions include students' autonomous motivation, controlled motivation, and amotivation as independent variables, and students' (4) LRST scores ($n = 215$), and (5) scores on the two-pager task as dependent variables ($n = 206$). Table 4 depicts the correlations for the first three analyses. Table 5 depicts the correlations for the last two analyses.

**Table 5**

*Correlations motivational and cognitive outcome variables*

|  | AM | CM | AMOT | LRST | Twopager |
|---|---|---|---|---|---|
| **AM** | 1 | | | | |

| | | | | | |
|---|---|---|---|---|---|
| **CM** | -.03 | 1 | | | |
| **AMOT** | -.21** | .41** | 1 | | |
| **LRST** | .10 | -.10 | -.32** | 1 | |
| **2pager** | .05 | .70 | -.11 | .28** | 1 |

** Correlation is significant at the 0.010 level (2-tailed).
* Correlation is significant at the 0.050 level (2-tailed)
Note. AM = autonomous motivation, CM = controlled motivation, AMOT = amotivation, LRST = score on LRST, Twopager = score on Twopager

**Table 6**

*Linear model of predictors of autonomous motivation, controlled motivation, amotivation, LRST scores, and two-pager scores with beta values, standard errors, standardized beta values and significance values*

| Regression | Dependent variable | Independent variable | $B$ | $B$ (SE) | $\beta$ | $p$ |
|---|---|---|---|---|---|---|
| 1 ($R^2 = .55$)* | AM | **AS*** | .39 | .09 | .30 | .000* |
| | | AF | -.02 | .06 | -.02 | .691 |
| | | **CS*** | .22 | .09 | .16 | .014* |
| | | CF | .13 | .07 | .11 | .060 |
| | | **RS*** | .11 | .05 | .11 | .026* |
| | | RF | .10 | .06 | .09 | .088 |
| | | **VU*** | .31 | .05 | .40 | .000* |
| 2 ($R^2 = .46$)* | CM | AS | .07 | .11 | .06 | .521 |
| | | **AF*** | .40 | .07 | .44 | .000* |
| | | CS | -.05 | .11 | -.04 | .667 |
| | | CF | .12 | .08 | .11 | .154 |
| | | **RS*** | .13 | .06 | .14 | .035* |
| | | RF | .12 | .07 | .11 | .097 |
| | | VU | .06 | .06 | .09 | .263 |
| 3 ($R^2 = .46$)* | AMOT | AS | -.04 | .14 | -.03 | .794 |
| | | **AF*** | .25 | .09 | .23 | .006* |
| | | CS | .24 | .13 | .16 | .072 |
| | | **CF*** | .21 | .10 | .17 | .033* |
| | | RS | .10 | .07 | .09 | .180 |
| | | RF | .03 | .09 | .03 | .699 |
| | | **VU*** | -.26 | .07 | -.31 | .000* |
| 4 ($R^2 = .33$)* | LRST | AM | .00 | .01 | .02 | .740 |
| | | CM | .01 | .02 | .04 | .629 |
| | | **AMOT*** | -.06 | .01 | -.33 | .000* |
| 5 ($R^2 = .12$) | 2-pager | AM | .06 | .14 | .03 | .687 |
| | | CM | .05 | .16 | .02 | .758 |
| | | AMOT | -.20 | .14 | -.12 | .137 |

Note. AM = autonomous motivation, CM = controlled motivation, AMOT = amotivation, VU = value/usefulness, AS = autonomy satisfaction, AF = autonomy frustration, CS = competence satisfaction, CF = competence frustration, RS = relatedness satisfaction, RF = relatedness frustration

Note. * = Significant at .050 level

In Table 3, we can see that students in both conditions experience average competence and autonomy satisfaction. However, students' relatedness satisfaction seems low in both conditions. This finding will be further discussed in the discussion section. For autonomous motivation, a significant regression equation was found $F(7,211) = 37.453$, $p < .001$. The regression analysis (see Table 6) further reveals that all three satisfaction scores (competence satisfaction, relatedness satisfaction and autonomy satisfaction) contribute positively to students' autonomous motivation, as does students' experienced value/usefulness. Also for

students' controlled motivation a significant regression equation was found $F(7,211) = 8.236$, $p < .001$, with students' autonomy frustration and students' relatedness satisfaction contributing to students' controlled motivation. The aforementioned relationships are in line with the expectations. However, we noticed that relatedness satisfaction contributed to students' controlled motivation in the opposite direction of what was expected (the higher students' relatedness satisfaction, the lower students' controlled motivation). This finding will be reflected upon in the discussion section. Also for students' amotivation, a significant regression equation was found $F(7,211) = 7.913$, $p < .001$. Students' autonomy frustration, competence frustration and students' value/usefulness contributed to students' amotivation in an expected way. Also for cognitive outcomes related to the research skills test, a significant regression equation was found $F(3,211) = 8.351$, $p < .001$. In line with the expectations, the regression analysis revealed that the higher students' amotivation, the lower students' scores on the research skills test. No significant regression equation was found for the outcome variable related to the research skills task $F(3,202) = .954$, $p < .416$. For all regression equations, the $R^2$ and the exact regression weights are presented in Table 6.

As a follow-up analysis and in order to better understand the outcomes, we decided to also look into the direct relationships between students' perceived needs and students' experienced value/usefulness, with students' cognitive outcomes (LRST and two-pager) by means of two additional regression analyses. The motivation behind this decision relates to possible issues regarding the motivational measures used, which might complicate the investigation of indirect relationships (see discussion). The results are provided in Table 7, and show that both for the LRST and the two-pager, respectively, a significant ($F(7,207) = 4.252$, $p < .001$) and marginally significant regression weight ($F(7,199) = 2.029$, $p = .053$) was found. More specifically, students' relatedness satisfaction and students' perceived value/usefulness contribute to students' scores on the two-pager and on the research skills test. As one would expect, we see that the higher students' value/usefulness, the higher students' scores on both cognitive outcomes. In contrast to one would expect, we found that the higher students' relatedness satisfaction, the lower students' scores on the cognitive outcomes. These findings are reflected upon in the discussion section.

**Table 7**

*Linear model of predictors of LRST scores, and two-pager scores with beta values, standard errors, standardized beta values and significance values*

| Regression | Dependent variable | Independent variable | $B$ | $B$ (SE) | $\beta$ | $p$ |
|---|---|---|---|---|---|---|
| 6 ($R^2 = .13$)* | LRST | AS | -.05 | .03 | -.19 | .055 |
| | | AF | -.01 | .02 | -.02 | .783 |
| | | CS | .03 | .02 | .11 | .239 |
| | | CF | .01 | .02 | -.04 | .667 |
| | | **RS*** | -.03 | .01 | -.16 | .025* |
| | | RF | .03 | .02 | .14 | .061 |
| | | **VU*** | .05 | .01 | .33 | .000* |
| 7 ($R^2 = .07$)* | 2-pager | AS | -.22 | .27 | -.09 | .413 |

| | | | | |
|---|---|---|---|---|
| AF | .07 | .17 | .04 | .667 |
| CS | .02 | .25 | .01 | .936 |
| CF | -.30 | .19 | -.14 | .116 |
| **RS\*** | -.31 | .14 | -.17 | .030* |
| RF | -.02 | .17 | -.12 | .906 |
| **VU\*** | .33 | .13 | .22 | .015* |

Note. AM = autonomous motivation, CM = controlled motivation, AMOT = amotivation, VU = value/usefulness, AS = autonomy satisfaction, AF = autonomy frustration, CS = competence satisfaction, CF = competence frustration, RS = relatedness satisfaction, RF = relatedness frustration

Note. * = Significant at .050 level

*RQ4: How do students experience need satisfaction and need frustration in a deliberately designed (4C/ID based) learning environment?*

As was mentioned in the method section, the fourth research question was analysed by labelling students' qualitative feedback by the codes 'autonomy satisfaction, autonomy frustration, competence satisfaction, competence frustration, relatedness satisfaction, and relatedness frustration'. By means of this approach, we could analyse students' need experiences in a fine grained manner. When students' quotes were applicable to more than one code, they were labelled with different codes. In what follows, students' quotes are indicated with the codes "BC" (baseline condition) or "NSC" (need satisfaction condition) in order to indicate which learning environment the student completed. Of all 233 students, 124 students provided qualitative feedback (44 in BC and 80 in NSC). In total, 266 quotes were labeled. Autonomy satisfaction was coded 40 times BC and 41 times in NSC; autonomy frustration was coded 13 times in BC and four times in NSC; competence satisfaction was coded 28 times in BC and 34 times in NSC; competence frustration was coded 31 times in BC and 27 times in NSC; relatedness satisfaction was coded 10 times in BC and 16 times in NSC; and relatedness frustration was coded five times in BC and 17 times in NSC. Several observations could be drawn from the qualitative data.

Related to **autonomy satisfaction**, in both conditions, several students explicitly mentioned the personal value and usefulness of what they had learned in the learning environment. While in the baseline condition, these references were often vague ("Now I know what people expect from me *next year*"; "I think I might use this information in *the future*"); some references appeared to be more specific in the need support condition ("I want to study *psychology* and I think I can use this information!"; "This is a good preparation for *higher education and university*"; "I can use this information to write an *essay*"; "I think the theory was interesting, because *you are sure you will need* it once. I don't always have that feeling during a normal lesson in school"). In addition, students in both conditions mentioned that they found the material interesting, and that they appreciated the online format: "It's different then just listening to a teacher, I kept interested because of the large variety in exercises and overall, I found it fun" (NSC).

Several comments were coded as '**autonomy frustration**' in both conditions. Some students indicated that they found the material "useless" (BC), or that "they did not remember that much" (BC). Others found the material "uninteresting" (BC), "heavy and boring" (NSC) or "not fun" (BC). In addition, some students "did not like to complete the assignments" (NSC), or "prefer a book to learn theory" (NSC).

Related to **competence satisfaction**, students in both conditions found the material "clear" (BC, NSC). In addition, students' appreciated the example answers, the difficulty rate ("Some exercises were hard, but that is good. That's a sign you're learning something new" (NSC)), and the fact that the theory was segmented in several parts. In addition, students recognized that the material required complex skills: "I learned a lot, you had to think deeper or gain insights in order to solve the exercises" (NSC), "you really had to think to complete the exercises" (NSC). In the need satisfaction group, several quotes were labelled related to the specific need support provided. For example, students indicated that they appreciated the forum option: "If something was not clear, you could check your peer's answers" (NSC). Students also valued the fact that they could work at their own pace: "I found it very good that we could solve everything at our own pace" (NSC); "good that you could choose your own pace, and if something was not clear to you, you could reread it at your own pace" (NSC). In addition, students appreciated the immediate feedback provided by the researcher "I found it very good that we received personal feedback from xxx (name researcher). That way, I knew whether I understood the theory correctly" (NSC); and the fact that they could indicate their progress "It was good that you could see how far you proceeded in the learning environment" (NSC).

In both the baseline and the need supportive condition, there were also several comments related to **competence frustration**. For example, students found exercises vague, unclear or too difficult. While students, overall, understood the theory provided, applying the theory to an integrative assignment appears to be very difficult: "I did understand the several parts of the learning environment, but I did not succeed in writing a research proposal myself" (NSC). "I just found it hard to respond to questions. When I had to write my two-pager research proposal, I really struggled. I really felt like I was doing it entirely wrong" (NSC)). In addition, a lot comments related to the fact that the theory was a lot to process in a short time frame, and therefore, students indicated that it was hard to remember all the theory provided. In addition, this led pressure in some students: "Sometimes, I experiences pressure. When you see that your peers are finished, you automatically start working faster." (BC).

Concerning **relatedness satisfaction**, in the baseline condition, students appreciated the chat function "you could help each other and it was interesting to hear each other's opinions about the topics we were working on" (BC). However, most students indicated that they did not make use of the chat or forum options. In the need satisfaction condition, students appreciated the forum and the chat function: "You knew

you could always ask questions. This helped to process the learning material" (NSC), "My peers' answers inspired me" (NSC), "Thanks to the chat function, I felt more connected to my peers" (NSC). In addition, students in the need satisfaction condition appreciated the fact that they could contact the researcher any time.

Several students made comments related to **relatedness frustration**. In both groups, students missed the 'live teaching': "I tried my best, but sometimes I did not like it, because you do not receive the information in 'real time', but through videos" (BC). In addition, students missed their peers: "We had to complete the environment individually" (BC). While some students appreciated the opportunity of a forum, other students found this possibility stressful: "I think the forum is very scary. I posted everything I had to, but I found it very scary that everyone can see what you post" (NSC). Others did not like the fact that they needed to work individually: "Sometimes I lost my attention because no one was watching my screen with me" (NSC); "I found it hard because this was new information and we could not discuss it with each other" (NSC); "I felt lonely" (NSC); "It is hard to complete exercises without the help of a teacher. In the future this will happen more often, so I guess I will have to get used to it" (NSC); "When I see the teacher physically, I feel less reluctant to ask questions" (NSC).

**Discussion**

The current intervention study aimed at exploring the motivational and cognitive effects of providing need support in an online learning environment fostering upper secondary school students' research skills. More specifically, we investigated the impact of autonomy, competence and relatedness support in an online learning environment on students' scores on a research skills test, a research skills task, students' autonomous motivation, controlled motivation, amotivation, need satisfaction, need frustration, and experienced value/usefulness. Adopting a pretest-intervention-posttest design approach, 233 upper secondary school behavioral sciences students' motivational outcomes were compared among two conditions: (1) a 4C/ID inspired online learning environment condition (baseline condition), and (2) a condition with an identical online learning environment additively providing support for students' autonomy, relatedness and competence need satisfaction (need supportive condition). This study aims to contribute to the literature by exploring the integration of need support for all three needs (the need for competence, relatedness and autonomy) in an ecologically valid setting. In what follows, the findings are discussed taking into account the COVID-19 affected circumstances in which the study took place.

*Cognitive outcomes*

As was hypothesized based on existing research (Costa et al., 2021), results showed significant learning gains on the LRST cognitive measure in both conditions, pointing out that the learning environments in

general succeeded in improving students' research skills. The current study did not find any significant differences in these learning gains between both conditions. Controlling for a priori differences between the conditions on the LRST pretest measure, students in the need support condition did exceed students in the baseline condition on the two-pager task. However, overall, the scores on the research skills task were quite low, pointing to the fact that students still seem to struggle in writing a research proposal. This task can be considered more complex (van Merriënboer & Kirschner, 2018) than the research skills test, as students are required to combine their conceptual and procedural knowledge in one assignment. Indeed, in the qualitative feedback, students indicate that they understand the theory and are able to apply the theory in basic exercises, but that they struggle in integrating their knowledge in a research proposal. Future research could set up more extensive interventions explicitly targeting students' progress while writing a research proposal, for example using development portfolios (van Merriënboer et al., 2006).

*Motivational outcomes*

The effect of the intervention on the motivational outcome measures was investigated. Since we experimentally manipulated need support, this study hypothesized that students in the need supportive condition would show higher scores for autonomous motivation, value/usefulness and need satisfaction; and lower scores for controlled motivation, amotivation and need frustration compared to students in the baseline condition (Deci & Ryan, 2000). However, the analyses showed that students in the conditions did not differ on the value/usefulness, autonomy satisfaction, autonomy frustration, competence satisfaction, competence frustration and relatedness frustration measures. In contrast to what was hypothesized, students' in the baseline condition reported higher relatedness satisfaction compared to students in the need supportive condition. No differences were found in students' autonomous motivation and controlled motivation. However, as was expected, students in the need supportive conditions did report lower levels of amotivation compared to students in the baseline condition. Still, for the current study, one could question the role of the need support in this respect, as the current intervention did not succeed in manipulating students' need experiences. In what follows, possible explanations for these findings are outlined in light of the existing literature.

Need experiences

A first observation based on the findings as described above is that the intervention did not succeed in manipulating students' need satisfaction, need frustration and value/usefulness in an expected way. One effect was found of condition on relatedness satisfaction, but in the opposite direction of what was expected. We did not find a conclusive explanation for this unanticipated finding, but we do argue that the COVID-19 related measures at play during the intervention could have impacted this result. This will be reflected

upon later in this discussion (limitations). In both conditions, students seem to be averagely satisfied regarding autonomy and competence in the 4C/ID based learning environments. This might be explained by the fact that 4C/ID based learning environments inherently foster students' perceived competence because of the attention for structure and guidance, and the fact that the use of authentic tasks can be considered autonomy supportive (Bastiaens & Martens, 2007). However, we see that students experience low relatedness satisfaction in both conditions. The fact that the learning environment was organized entirely online might have influenced this result. While one might also partly address this low relatedness satisfaction to the COVID-19 circumstances at play during the study, this hypothetical explanation does not hold entirely since also in a previous non COVID-affected study in this research trajectory (Maddens et al., under review), students' relatedness satisfaction was found to be low. This finding, combined with findings from students' qualitative feedback clearly indicating relatedness frustration, we argue that future research could focus on the question as how to provide need for relatedness support in 4C/ID based learning environments. On a more general level, this raises the question how opportunities for discussions and collaboration can be included in 4C/ID based learning environments. For example, organizing 'real classroom interactions' or performing assignments in groups (see also the suggestion of van Merriënboer & Kirschner, 2018), might be important in fostering students' relatedness satisfaction (Salomon, 2002). As argued by Wang and colleagues (2019), relatedness support is clearly understudied, for a long time often even ignored, in the SDT literature. Recently, relatedness is beginning to receive more attention, and has been found a strong predictor of autonomous motivation in the classroom (Wang et al., 2019).

Possibly, the need support provided in the learning environment was insufficient or inadequate to foster students' need experiences. However, as the implementations were based on the existing literature (Deci & Ryan, 2000), this finding can be considered surprising. In addition, we derive from the qualitative feedback that students seem to value the need support provided in the learning environment. These contradictory observations are in line with previous research (Bastiaens & Martens, 2007), and call for further investigation.

Autonomous motivation, controlled motivation, amotivation

A second observation is that, in both conditions, students seem to hold low autonomous motivation and low controlled motivation towards learning research. On average, also students' amotivation is low. The fact that students are not amotivated to learn about research can be considered reassuring. However, the fact that students experience low autonomous motivation causes concerns, as we know this might negatively impact their learning behavior and intentions to learn (Deci & Ryan, 2000; Wang et al., 2019). However, this result is based on mean scores. Future research might look at these results at student level, in order to identify

individual motivational profiles (Vansteenkiste et al., 2009) and their prevalence in upper secondary behavioral sciences education.

A third observation is that students' autonomous and controlled motivation were not affected by the intervention. Since the intervention did not succeed in manipulating students' need experiences, this finding is not surprising. In addition, this is in line with Bastiaens and Martens' (2007) study, not finding motivational effects of providing need support in 4C/ID based learning environments. However, the current study did confirm that – although still higher than at pretest level, see below - students in the need supportive condition reported lower amotivation compared to students in the baseline condition. As no amotivational differences were observed at pretest level, this might indicate that students' self-reported motivation (autonomous and controlled motivation) and/or needs do not align with students' experienced motivation and needs. As was mentioned, this calls for further research.

Theoretical relationships

In line with previous research (Wang et al., 2019), multiple regression analyses revealed that students' need satisfaction (on all three measures) contributed positively to students' autonomous motivation. In addition, also students' perceived value/usefulness contributed positively to students' autonomous motivation. Students' competence frustration and autonomy frustration contributed positively to students' amotivation, and students' value/usefulness contributed negatively to students' amotivation. Students' autonomy frustration contributed positively to students' controlled motivation. While all the aforementioned relationships are in line with the expectations (Deci & Ryan, 2000; Wang et al., 2019), an unexpected finding is that students' relatedness satisfaction contributed positively to students' controlled motivation. This contradicts previous research (Wang et al., 2019), reporting that relatedness contributes to controlled motivation negatively. However, previous research (Wang et al., 2019) did find controlled motivation to be positively related to *pressure*. Although we did not find a conclusive explanation for this unanticipated finding, one possible reason thus is that students who contacted their peers in the online learning environment (and thus felt more related to their peers), might have experienced pressure because they felt like their peers worked faster or in a different way. Indeed, in the qualitative feedback, we noticed that some students indicated they 'rushed' through the online learning environment because they noticed a peer working faster. This finding calls for further research.

Overall, the results indicate that the observed need variables contributed most to students' autonomous motivation, compared to (reversed relationships in) students' amotivation and students' controlled motivation. As such, when targeting students' motivation, fostering students' autonomous motivation based on students' need experiences seems most promising. This is in line with previous research

(Wang et al., 2019) reporting high correlations between students' needs and students' autonomous motivation, compared to students' controlled motivation. We also investigated the relationships between students' motivation and students' cognitive outcomes. In line with a previously conducted study in this research trajectory (Maddens et al., under review), but in contrast to what was hypothesized based on the existing literature (Deci & Ryan, 1994; Grolnick et al., 1991; Reeve, 2009) we found that nor students' autonomous motivation, nor students' controlled motivation contributed to students' scores on the research skills test. However, we did find that students' amotivation contributed negatively to students' LRST scores. As such, when targeting students' cognitive outcomes in educational programs, one might pay explicit attention to preventing amotivation. This is in line with previous research conducted in other domains, reporting that amotivation plays an important role in predicting mathematics achievement (Leroy & Bressoux, 2016), while this relationship was not found in other motivation types. Related to research skills, the current research suggests that preventing competence frustration and autonomy frustration, and fostering students' experiences of value/usefulness might be especially promising to reach this goal.

Initially, we did not plan any analyses investigating the direct relationships between students' needs and students' cognitive outcomes, partly because previous research (Vallerand & Losier, 1999) suggests that the relationships between need satisfaction and (cognitive) outcomes are mediated by the types of motivation. To this end, we investigated the relationships between students' needs and students' motivation, separately from the relationships between students' motivation and students' cognitive outcomes. However, because of potential issues with the motivational measures (see earlier), which possibly hampers the interpretation of the relationships between students' needs, students' motivation, and students' cognitive outcomes, we decided to also directly assess the regression weights of students' needs and students' perceived value/usefulness, on students' cognitive outcomes. Results revealed that, in line with the expectations, students' perceived value/usefulness contributed positively to students' LRST scores and two-pager scores, which potentially stresses the importance of value/usefulness, not only for motivational purposes, but also for cognitive purposes. This is in line with previous research (Assor and colleagues, 2002), establishing relationships between fostering relevance and students' behavioral and cognitive engagement (which potentially leads to better cognitive outcomes). In contrast to the expectations, students' relatedness satisfaction was found to be negatively related to students' scores on the LRST and the two-pager. However, again, this surprising finding is best interpreted in light of the COVID-10 pandemic (see earlier).

*Limitations*

COVID-19

This study faced some reliability issues given the time frame in which the study took place. Due to the COVID-19-restrictions at play at the time of study, the study plan needed to be revised several times in collaboration with teachers in order to be able to complete the interventions. In addition, it is very likely that students' motivation (and relatedness satisfaction) was influenced by the COVID 19-restrictions. For example, due to the restrictions, in the last phase of the intervention, students could only be present at school halftime, and therefore, some students worked from home while others worked in the classroom. In the qualitative feedback, students reported several COVID-19 related frustrations (it was too cold in class because teachers were obligated to open the windows; students needed to frequently disinfect their computers…). Also the teachers mentioned that students suffered from low well-being during the COVID-19 time frame (see further), and as such, this affected their motivation. Although all efforts were undertaken in order for the study to take place as controlled as possible, results should be interpreted in light of this time frame. The impact of the COVID-19 pandemic on students' self-reported motivation has been established in recent research (Daniels et al., 2021). Overall, one could question to what extent we can expect an intervention at microlevel (manipulating need support in learning environments) to work, when the study takes place in a time frame where students' need experiences are seriously threatened by the circumstances.

Decreasing motivation

Students' motivation evolved in a non-desirable way in both conditions. This unexpected finding (decreasing motivation) might be explained by four possible reasons: a first explanation is that asking students to fill out the same questionnaire at posttest and pretest level might lead to frustration and lower reported motivation (Kosovich et al., 2017). Indeed, students spent a lot of time working in the online learning environment, so filling out another motivational questionnaire on top of the intervention might have added to the frustration (Kosovich et al. 2017). A second explanation is that students' motivation naturally declines over time (which is a common finding in the motivational literature, Kosovich et al., 2017). A third explanation is that students, indeed, felt less motivated towards research skills after having completed the online learning environment. For example, the qualitative data indicated that a lot of students acknowledged the fact that the learning environment was useful, but that personally, they were not interested in learning the material. In addition, students indicated that the learning material was a lot to process in a short time frame, and was new to them, which might have negatively impacted their motivation. The latter (students indicating that the learning material was extensive) might indicate that students experienced high cognitive load (Paas & van Merriënboer, 1994; Sweller et al., 1998) while completing the learning environment. A fourth explanation is that, due to the COVID19-restrictions, students lost motivation during the learning process. A post-intervention survey in which we asked teachers about the impact of the COVID-

19 restrictions on students' motivation indicated that some students experienced low well-being during the COVID-19 pandemic, and thus, this might have hampered their motivation to learn. In addition, a teacher mentioned that COVID-19 in general was very demotivating for the students, and that students had troubles concentrating due to the fact they felt isolated. As was mentioned, the impact of COVID-19 on students' motivation has been well described in the literature (Daniels et al., 2021). Although, in the current study, we cannot prove the impact of these measures on students' motivation specifically towards learning research skills, it is important to take this context into account when interpreting the results.

Students' learning behavior

Based on students' qualitative feedback, we have reasons to believe that students did not always work in the learning environment as we would want them to do. Thus, students did not interact with the need support in the intended way ('instructional disobedient behavior': Elen, 2020). For example, several students reported that they did not always read all the material, did not make use of the forum, or did not notice certain messages from the researcher. However, the current research did not specifically look into students' learning behavior in the learning environment. In learning environments organized online, future researchers might want to investigate students' online behavior in order to gain insights in students' interactions with the learning environment.

**Conclusion**

This study aims to contribute to theory and practice. Firstly, this study defines the 4C/ID model (van Merriënboer & Kirschner, 2018) as a good theoretical framework in order to design learning environments aiming to foster students' research skills. However, this study also points to students' struggling in writing a research proposal, which might lead to more specific intervention studies especially focussing on monitoring students' progress while performing such tasks. Secondly, this study clearly elaborates on the operationalizations of need support used, and as such, might inform instructional designers in order to implement need support in an integrated manner (including competence, relatedness and autonomy support). Future interventions might want to track and monitor students' learning behavior in order for students to interact with the learning environment as expected (Elen, 2020). Thirdly, this study established theoretical relationships between students' needs, motivation and cognitive outcomes, which might be useful information for researchers aiming to investigate students' motivation towards learning research skills in the future. Based on the findings, future researchers might especially involve in research fostering students' autonomous motivation by means of providing need support; and avoiding students' amotivation in order to enhance students' cognitive outcomes. Suggestions are made based on the need support and frustration measures relating to these motivational and cognitive outcomes. For example, fostering students' value/usefulness seems promising for both cognitive and motivational outcomes. Fourthly, although we did

not succeed in manipulating students' need experiences, we did gain insights in students' experiences with the need support by means of the qualitative data. For example, the irreplaceable role of teachers in motivating students has been exposed. This study can be considered innovative because of its aim to inspect both students' cognitive and motivational outcomes after completing a 4C/ID based educational program (van Merriënboer & Kirschner, 2018). In addition, this study implements integrated need support rather than focusing on a single need (Deci & Ryan, 2000; Sheldon & Filak, 2010).

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**Declarations**

All ethical and GDPR-related guidelines were followed as required for conducting human research and were approved by SMEC (Social and Societal Ethics Committee).

**References**

Aelterman, N., Vansteenkiste, M., Van Keer, H., & Haerens, L. (2016). Changing teachers' beliefs regarding autonomy support and structure: The role of experienced psychological need satisfaction in teacher training. *Psychology of Sport and Exercise*, *23*, 64-72. https://doi.org/10.1016/j.psychsport.2015.10.007

Assor, A., Kaplan, H., & Roth, G. (2002). Choice is good, but relevance is excellent: Autonomy-enhancing and suppressing teacher behaviours predicting students' engagement in schoolwork. *British journal of educational psychology, 72*(2), 261-278. https://doi.org/10.1348/000709902158883

Aydın, S., Yerdelen, S., Yalmancı, S. G., & Göksu, V. (2014). Academic Motivation Scale for Learning Biology: A Scale Development Study. *Education & Science/Egitim ve Bilim*, *39*(176), 425-435. https://doi.org/10.15390/EB.2014.3678

Bastiaens, E., van Merriënboer, J., & van Tilburg, J. (2017). Three educational models for positioning the Maastricht research-based learning programme. In *Research-based learning: Case studies from Maastricht University* (pp. 35-41). Springer, Cham.

Blinded for review (under review)

Braguglia, K. H., & Jackson, K. A. (2012). Teaching research methodology using a project-based three course sequence critical reflections on practice. *American Journal of Business Education (AJBE)*, *5*(3), 347-352. https://doi.org/10.19030/ajbe.v5i3.7007

Butz, N. T., & Stupnisky, R. H. (2017). Improving student relatedness through an online discussion intervention: The application of self-determination theory in synchronous hybrid programs. *Computers & Education*, *114*, 117-138. https://doi.org/10.1016/j.compedu.2017.06.006

Chen, B., Vansteenkiste, M., Beyers, W., Boone, L., Deci, E. L., Van der Kaap-Deeder, J., ... & Verstuyf, J. (2015). Basic psychological need satisfaction, need frustration, and need strength across four cultures. *Motivation and emotion, 39*(2), 216-236. https://doi.org/10.1007/s11031-014-9450-1

Chi, M. T. (2009). Active-constructive-interactive: A conceptual framework for differentiating learning activities. *Topics in cognitive science, 1*(1), 73-105. https://doi.org/10.1111/j.1756-8765.2008.01005.x

Cook, D. A., & McDonald, F. S. (2008). E-learning: Is there anything special about the" e"?. *Perspectives in biology and medicine, 51*(1), 5-21. https://doi.org/10.1353/pbm.2008.0007

Costa, J. M., Miranda, G. L., & Melo, M. (2021). Four-component instructional design (4C/ID) model: a meta-analysis on use and effect. *Learning Environments Research*, 1-19. https://doi.org/10.1007/s10984-021-09373-y

Daniels, L. M., Goegan, L. D., & Parker, P. C. (2021). The impact of COVID-19 triggered changes to instruction and assessment on university students' self-reported motivation, engagement and perceptions. *Social Psychology of Education*, *24*(1), 299-318.

de Jong, T., & van Joolingen, W.R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of educational research, 68*(2), 179-201. https://doi.org/10.3102/00346543068002179

de Jong, T. (2006). Scaffolds for Scientific Discovery Learning. In J. Elen & R. E. Clark (Eds.), *Handling Complexity in Learning Environments: Theory and Research* (pp. 107-128). Emerald Group Publishing Limited.Deci, E. L., Eghrari, H., Patrick, B. C., & Leone, D. R. (1994). Facilitating internalization: The self-determination theory perspective. *Journal of Personality, 62*, 119–142.

Deci, E. L., Ryan, R. M., & Williams, G. C. (1996). Need satisfaction and the self-regulation of learning. *Learning and individual differences, 8*(3), 165-183. https://doi.org/10.1016/S1041-6080(96)90013-8

Deci, E. L., & Ryan, R. M. (2000). The" what" and" why" of goal pursuits: Human needs and the self-determination of behavior. *Psychological inquiry, 11*(4), 227-268. https://doi.org/10.1207/S15327965PLI1104_01

Deci, E. L., Olafsen, A. H., & Ryan, R. M. (2017). Self-determination theory in work organizations: The state of a science. *Annual review of organizational psychology and organizational behavior, 4*, 19-43.

Earley, M. A. (2014). A synthesis of the literature on research methods education. *Teaching in Higher Education, 19*(3), 242–253. https://doi.org/10.1080/13562517.2013.860105

Elen, J. (2020). "Instructional disobedience": a largely neglected phenomenon deserving more systematic research attention. *Educational Technology Research and Development, 68*(5), 2021-2032. https://doi.org/10.1007/s11423-020-09776-3

Engelmann, K., Neuhaus, B. J., & Fischer, F. (2016). Fostering scientific reasoning in education – meta-analytic evidence from intervention studies. *Educational Research and Evaluation, 22*(5–6), 333–349. https://doi.org/10.1080/13803611.2016.1240089

Field, A. (2013). *Discovering statistics using IBM SPSS statistics*. London: SAGE Publications.

Fischer, F., Kollar, I., Ufer, S., Sodian, B., Hussmann, H., Pekrun, R., Neuhaus, B., Dorner, B., Pankofer, S., Fischer, M., Strijbos, J-W., Heene, M., & Eberle, J. (2014). Scientific reasoning and argumentation: Advancing an interdisciplinary research agenda in education. *Frontline Learning Research, 4*, 28–45. https://doi.org/http://dx.doi.org/10.14786/flr.v2i2.96

Fischer, F., Chinn, C. A., Engelmann, K., & Osborne, J. (2018). *Scientific reasoning and argumentation. The roles of domain-specific and domain-general knowledge*. Routledge.

Gardner, B., & Tang, V. (2014). Reflecting on non-reflective action: An exploratory think-aloud study of self-report habit measures. *British journal of health psychology*, *19*(2), 258-273. https://doi.org/10.1111/bjhp.12060

Grolnick, W. S., Ryan, R. M., & Deci, E. L. (1991). Inner resources for school achievement: Motivational mediators of children's perceptions of their parents. *Journal of educational psychology*, *83*(4), 508-517.

Kosovich, J. J., Hulleman, C. S., & Barron, K. E. (2017). Measuring motivation in educational settings: A Case for pragmatic measurement. *The Cambridge handbook on motivation and learning*, 39-60.

Lehti, S., & Lehtinen, E. (2005). Computer-supported Problem-based Learning in the Research Methodology Domain. *Scandinavian Journal of Educational Research, 49*(3), 297-324. https://doi.org/10.1080/00313830500109618

Leroy, N., & Bressoux, P. (2016). Does amotivation matter more than motivation in predicting mathematics learning gains? A longitudinal study of sixth-grade students in France. *Contemporary Educational Psychology*, *44*, 41-53. https://doi.org/10.1016/j.cedpsych.2016.02.001

Lesterhuis, M., Daal, T. van, Van Gasse, R., Coertjens, L., Donche, V., & De Maeyer, S. (2018). When teachers compare argumentative texts: Decisions informed by multiple complex aspects of text quality. *L1-Educational Studies in Language and Literature,* 18, 1-22. https://doi.org/10.17239/L1ESLL-2018.18.01.02

Maddens, L., Depaepe, F., Janssen, R., Raes, A., & Elen, J. (2020a). Evaluating the Leuven Research Skills Test for 11th and 12th Grade. *Journal of Psychoeducational Assessment, 38*(4), 445-459.

Maddens, L., Depaepe, F., Raes, A., & Elen, J. (2020b). The Instructional Design of a 4C/ID-Inspired Learning Environment for Upper Secondary School Students' Research Skills. *International Journal of Designs for Learning, 11*(3), 126-147.

Maddens, L., Depaepe, F., Raes, A., & Elen, J. (under review). Fostering students' motivation towards learning research skills in upper secondary school behavioral sciences education: the role of autonomy support.

Martin, N., Kelly, N., & Terry, P. (2018). A framework for self-determination in massive open online courses: Design for autonomy, competence, and relatedness. *Australasian Journal of Educational Technology, 34*(2). https://doi.org/10.14742/ajet.3722

Merrill, M. D. (2002). First principles of instruction. *Educational technology research and development*, *50*(3), 43-59. https://doi.org/10.1007/BF02505024

Murtonen, M. S. S. (2005). *Learning of quantitative research methods: University students' views, motivation and difficulties in learning.* (Doctoral Dissertation)

Niemiec, C. P., & Ryan, R. M. (2009). Autonomy, competence, and relatedness in the classroom: Applying self-determination theory to educational practice. *Theory and research in Education*, *7*(2), 133-144. https://doi.org/10.1177%2F1477878509104318

Phuoc, C. T. N. (2020). Basic Psychological Need Satisfaction and Frustration Scale-Adolescents (THE BPNSFS-A): Validity in the Vietnamese Context. *Asia-Pacific Social Science Review*, *20*(3), 2227-2240.

Pietersen, C. (2002). Research as a learning experience: A phenomenological explication. *The qualitative report*, *7*(2), 1-14. https://doi.org/10.46743/2160-3715/2002.1980

Raes, A., & Schellens, T. (2015). Unraveling the motivational effects and challenges of web-based collaborative inquiry learning across different groups of learners. *Educational Technology Research and Development, 63*(3), 405-430. https://doi.org/10.1007/s11423-015-9381-x

Reeve, J., Jang, H., Hardre, P., & Omura, M. (2002). Providing a rationale in an autonomy-supportive way as a strategy to motivate others during an uninteresting activity. *Motivation and emotion*, *26*(3), 183-207.

Reeve, J. (2006). Extrinsic Rewards and Inner Motivation. In C. M. Evertson & C. S. Weinstein (Eds.), *Handbook of classroom management: Research, practice, and contemporary issues* (pp. 645–664). Lawrence Erlbaum Associates Publishers.

Reeve, J., & Jang, H. (2006). What teachers say and do to support students' autonomy during a learning activity. *Journal of educational psychology, 98*(1), 209-218. https://doi.org/10.1037/0022-0663.98.1.209

Ringeisen, T., & Bürgermeister, A. (2015). Fostering students' self-efficacy in presentation skills: The effect of autonomy, relatedness and competence support. *Stress and anxiety: Application to schools, well-being, coping and internet use*, 77-87.

Ryan, R. M. (1982). Control and information in the intrapersonal sphere: An extension of cognitive evaluation theory. *Journal of Personality and Social Psychology, 43*, 450-461. https://psycnet.apa.org/doi/10.1037/0022-3514.43.3.450

Ryan, R. M. (1995) Psychological needs and the facilitation of integrative processes. *Journal of Personality*, 63, 397-427

Ryan, R. M., & Grolnick, W. S. (1986). Origins and pawns in the classroom: Self-report and projective assessments of individual differences in children's perceptions. *Journal of Personality and Social Psychology, 50*, 550–558.

Salomon, G. (2002). Technology and pedagogy: Why don't we see the promised revolution?. *Educational technology*, *42*(2), 71-75.

Schunk, D. H. (2003). Self-efficacy for reading and writing: Influence of modeling, goal setting, and self-evaluation. *Reading & Writing Quarterly*, *19*(2), 159-172. https://doi.org/10.1080/10573560308219

Sheldon, K. M., & Filak, V. (2008). Manipulating autonomy, competence, and relatedness support in a game-learning context: New evidence that all three needs matter. *British Journal of Social Psychology*, *47*(2), 267-283. https://doi.org/10.1348/014466607X238797

Steingut, R. R., Patall, E. A., & Trimble, S. S. (2017). The effect of rationale provision on motivation and performance outcomes: A meta-analysis. *Motivation Science, 3*(1), 19-50. https://doi.org/10.1037/mot0000039

Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and instruction, 4*(4), 295-312.

Vallerand, R. J. (1997). Toward a hierarchical model of intrinsic and extrinsic motivation. In *Advances in experimental social psychology* (Vol. 29, pp. 271-360). Academic Press.

Vallerand, R. J., & Losier, G. F. (1999). An integrative analysis of intrinsic and extrinsic motivation in sport. *Journal of applied sport psychology, 11*(1), 142-169. https://doi.org/10.1080/10413209908402956

Vallerand, R. J., & Reid, G. (1984). On the causal effects of perceived competence on intrinsic motivation: A test of cognitive evaluation theory. *Journal of Sport Psychology, 6,* 94–102.

van Merriënboer, J., Sluijsmans, D., Corbalan, G., Kalyuga, S., Paas, F., & Tattersall, C. (2006). Performance Assessment and Learning Task Selection in Environments for Complex Learning. In J. Elen & R. E. Clark (Eds.), *Handling complexity in learning environments: Theory and Research.* Oxford, G.B.: Elsevier Science Ltd. https://doi.org/10.1037/0003-066X.55.1.68

Van Merriënboer, J. J. G., & Kirschner, P. A. (2018). *Ten steps to complex learning*. Routledge

Vansteenkiste, M.Ryan, R. M.Soenens, B. (2020) Basic psychological need theory: Advancements, critical themes, and future directions. *Motivation and Emotion*, 44, 1-31

Vansteenkiste, M., Sierens, E., Soenens, B., Luyckx, K., & Lens, W. (2009). Motivational profiles from a self-determination perspective: The quality of motivation matters. *Journal of Educational Psychology, 101*(3), 671–688. https://doi.org/10.1037/a0015083

Vansteenkiste, M., Sierens, E., Goossens, L., Soenens, B., Dochy, F., Mouratidis, A., ... & Beyers, W. (2012). Identifying configurations of perceived teacher autonomy support and structure: Associations with self-regulated learning, motivation and problem behavior. *Learning and instruction*, *22*(6), 431-439. https://doi.org/10.1016/j.learninstruc.2012.04.002

Wang, C. J., Liu, W. C., Kee, Y. H., & Chian, L. K. (2019). Competence, autonomy, and relatedness in the classroom: understanding students' motivational processes using the self-determination theory. *Heliyon*, *5*(7), e01983. https://doi.org/10.1016/j.heliyon.2019.e01983

**Appendix 1: overview test instruments**

    1.    Example items academic self-regulation scale (adapted from Vansteenkiste et al., 2009)

I am motivated to learn about research skills…

| External regulation | Because that's what others (e.g., parents, friends) expect from me. |
|---|---|
| Introjected regulation | Because I want others to think I'm smart. |
| Identified regulation | Because it's personally important to me. |
| Intrinsic motivation | Because I think it is interesting. |

    2.    Example item Academic Motivation Scale for learning biology (Aydin et al., 2014)

| Amotivation | To be honest, I don't see any reason for learning about research skills. |
|---|---|

    3.    Example item Intrinsic Motivation Inventory (adapted from Ryan, 1982)

| Value/Usefulness | I believe completing this learning environment could be of some value to me. |
|---|---|

    4.    Example item BPNSNF (adapted from Chen et al., 2015)

| Autonomy satisfaction | While completing the learning environment, I felt a sense of choice and freedom in the things I thought and did. |
|---|---|

    5.    Example item LRST (Maddens et al., 2020a)

Choose the best research question for each situation sketched below:

    a.  A researcher is interested in the relationship between grade retention and motivation of students in secondary education.
- ☐ How does redoing a school year affect the motivation of students in secondary education and how do students handle with this?
- ☐ Does redoing a school year have positive effects on the motivation of students in secondary education?
- ☐ How motivated are students in secondary education after redoing a school year?
- ☐ What is the relation between redoing a school year and students' motivation?

    6.    Instructions 2-pager (Blinded for review)

Write a research proposal for a fictional study.

In a Word-document of maximum two pages…

- You describe a research question and the importance of this research question
- You explain how you would answer this research question (manner of data collection and target group)
- You explain what your expectations are, and how you will report your results.

To do so, you receive two hours.

Post your research proposal here.

Good luck and thank you for your activity in the RISSC-environment!