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Learning and instruction in the hybrid virtual classroom: An investigation of students' engagement and the effect of quizzes

Annelies Raes[a,b,*,1], Pieter Vanneste[a,b,1], Marieke Pieters[a], Ine Windey[a,b], Wim Van Den Noortgate[a,b], Fien Depaepe[a,b]

[a] KU Leuven, Faculty of Psychology and Educational Sciences, Belgium
[b] KU Leuven, IMEC Research Group ITEC

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ABSTRACT

To deal with the current need for flexible learning trajectories giving access to a more diverse group of learners, synchronous hybrid virtual classrooms have been designed to connect both on-site students and remote students during synchronous teaching. Given synchronous blended learning is relatively new, there are only few studies that have investigated its use and effectiveness. Furthermore, the existing literature is mostly exploratory and qualitative in nature. This present study meets the need for empirical, theory-driven research. More specific, this study has set up an experiment to investigate how different learning settings can affect students' relatedness, intrinsic motivation and learning achievement in the context of a synchronous learning space. The Self-Determination Theory (SDT) namely stresses that relatedness is a contributing factor for intrinsic motivation and indirectly also predicts learning achievement. Although there are numerous studies using SDT in various contexts, only limited studies used this theory to examine learning in the hybrid virtual classroom comparing different learning settings and its effects on relatedness, intrinsic motivation and learning achievement. The educational setting depends on whether students are physically present and thus attend the lecture face-to-face (F2F) or remotely (virtual), and on whether the setting is the same for all students (pure) or mixed (hybrid). This study presents the results of an experimental within-subjects design study comparing the students' learning experiences as F2F versus virtual student in the pure or hybrid setting. A mixed-methods approach is used including real-time measurements of intrinsic motivation next to retrospective self-report surveys and interviews. Also the effect of quizzes has been consistently investigated. The results show that although the hybrid virtual classroom is promising regarding flexibility in education as it gives students the choice where to attend the course, it is also the most challenging one to teach in and to learn in as a remote participant. It has been found that both the relatedness to peers and the intrinsic motivation is the lowest in the hybrid-virtual setting. Yet, our results show that launching quizzes is positively related to all students' motivation. Further research that implements different kinds of quizzes and at different time intervals is necessary to validate this finding in the context of the hybrid virtual classroom. Future research should also investigate how relatedness between the remote students and their on-campus counterparts can be improved by means of instructional interventions.

* Corresponding author. KU Leuven Campus Kulak Kortrijk, Faculty of Psychology and Educational Sciences, Etienne Sabbelaan 51, 8500 Kortrijk, Belgium.
E-mail address: annelies.raes@kuleuven.be (A. Raes).
[1] co-first authors.

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1. Introduction

In the context of lifelong learning, upper secondary education, higher education and vocational training are challenged to think about how to enable people, at any stage of their life, to take part in stimulating learning experiences. The expectation to be present at one core location is getting more and more difficult in our international and interconnected society. In addition, the student population is changing and balancing study, work and family life becomes a point of priority. Therefore, it is important to make education less dependent on location and time and improve flexibility within the learning trajectory (Lakhal, De Sherbrooke, & Bateman, 2017). Meanwhile, there are growing insights about the need to collaborate over the borders of institutions, to implement expertise from partner organisations and to face expanding enrolments and contracting institutional budgets (Stupnisky & Butz, 2016).

Within this context, digital technologies are often put forth as a possible answer to change the educational landscape and make it more flexible and accessible for a larger group of learners (Cain, 2015). MOOCs for example have been very popular and profoundly studied during the last decade (e.g., Kizilcec, Pérez-Sanagustín, & Maldonado, 2017). Some have started to see MOOCs as a replacement for traditional institutions in higher education and it has even been questioned whether traditional institutions will survive the e-learning revolution. Yet, many research findings relativize this view. Firstly, although online courses have the potential to increase educational accessibility to distance and lifelong learners (Koller, Ng, Do, & Chen, 2013), research also demonstrates that student engagement in pure online courses remains mixed (Cunningham, 2014; Lakhal, Bateman, & Bédard, 2017). Second, completion rates for online courses are usually significantly lower than for courses where instruction occurs face-to-face (Dietz-Uhler, Fisher & Han, 2007). Lastly, personal contact and interaction, which characterizes face-to-face dialogue and occurs in traditional lectures, is still lacking in most e-learning settings (Ramsey, Evans, & Levy, 2016). This is an important factor because learners attach great value to personal contact, both with the teacher and with their fellow students (Marshall, 2018).

These findings stress the preservation of educational institutions as places in which students and teachers meet and interact with each other. Hence, learning institutions should offer more flexible learning trajectories giving students the chance to choose to come to campus or to attend the course remotely. One way to do this, is by organizing learning in a *synchronous hybrid learning space,* also conceptualised as *"Here or There (HOT) instruction"* (Zydney, McKimmy, Lindberg, & Schmidt, 2019). Recently, we conducted a systematic literature review on synchronous hybrid learning (Raes, Detienne, Windey, & Depaepe, 2019) that aimed to synthesize the best available evidence to have an overview of the state-of-the-art and the current gaps in the current research, In line with several researchers (Abdelmalak & Parra, 2016; Bower, Dalgarno, Kennedy, Lee, & Kenney, 2015; Butz & Askim-Lovseth, 2015; Butz & Stupnisky, 2017; Olt, 2018; Zydney, McKimm, Lindberg, & Schmidt, 2019), the review study concluded that the research into synchronous hybrid learning is still in its infancy. It was found that most of the existing literature is exploratory and qualitative in nature and has focused mostly on the description of students' experiences, the organisational implementation and the technological design. It is stressed that empirical studies have only begun to emerge and that more research founded by theory is needed examining different pedagogical scenarios and its impact on student outcomes.

This study aims to meet this research gap by experimentally investigate how different learning settings can affect students' relatedness, intrinsic motivation or learning achievement in the context of a synchronous learning space. In what follows, we start with the theoretical framework (Section 2), that includes an overview of the state-of-the-art of the current research, and summarizes the benefits and key challenges. It also presents the variables under investigation framed within the self-determination theory, and explains the current research on quizzes in lectures. In Section 3, first related work and other existing solutions are presented. Second, limitations of previous research and existing solutions are outlined, and third, the current study and technological solution under investigation is described in detail. In the Methodology section (Section 4) the research questions and hypotheses are presented, followed by a description of the experimental design, participants, procedure and data-analysis used in this study. Section 5 presents the results of the study and in Section 6, we elaborate on these results in relation to previous findings and define the main implications for future research and practice. Finally, Section 7 provides a brief conclusion.

2. Theoretical framework

2.1. The hybrid virtual classroom and its benefits

To deal with the need for more flexible learning, educational research and development aimed at providing a richer, more engaging remote learning experience by the creation of the *synchronous hybrid virtual classroom*. The concept of the hybrid virtual classroom comprises one group of learners who participates in the course on campus, and simultaneously other individual learners participate in the course remotely from a location of their own choice by connecting to the same platform (Butz, Stupnisky, Pekrun, Jensen, & Harsell, 2016; Hastie, Hung, Chen, & Kinshuk, 2010).

Raes et al. (2019) have conducted a systematic review on the existing research to summarize benefits and challenges; and to formulate instructional design principles. The reported benefits could be categorized into two categories, namely (1) organisational benefits related to educational access and efficiency in teaching; and (2) pedagogical benefits related to quality of learning.

2.1.1. Organisational benefits

The synchronous hybrid virtual classroom offers the possibility to reach out to a greater base of potential students at it offers more flexibility because it gives working students, as well as students who are for example abroad or ill for a longer period of time, the opportunity to participate in the actual lesson and to interact from a distance with all students and the teacher (Butz & Askim-

Lovseth, 2015; Wang, Quek, & Hu, 2017; Wiles & Ball, 2013; Ørngreen, Levinsen, Jelsbak, Moller, & Bendsen, 2015). Also it can ensure more inclusive education and equality in learning (Bower et al., 2015; Weitze, Ørngreen, & Levinsen, 2013). Moreover, it is possible to offer more elective or specific courses which are normally taught at one specific location. In addition, external experts can be consulted more easily in the learning process, which can better address the personal interests of the students and learners (Bell, Sawaya, & Cain, 2014; McGovern & Barnes, 2009). Education can also be organized more efficiently as the synchronous hybrid virtual classroom eliminates the need to teach the same course twice, as many teachers need to travel to various campuses to deliver the same course to different classes (Bell et al., 2014; Wiles & Ball, 2013). In addition, teachers and students do not have to move to the campus and consequently enjoy the freedom and flexibility this learning environment offers.

2.1.2. Pedagogical benefits

The hybrid virtual classroom offers the possibility to include expertise outside the institution meaning that students are being exposed to a broader range of views and ideas, because this collaboration and connection between face-to-face and remote students creates richer learning experiences (Bell et al., 2014; Bower et al., 2015). Likewise, this flexibility ensures that hybrid virtual learning can guarantee continuity of instruction and promotes student retention (Lakhal et al., 2017).

Only limited studies have done empirical research to assess the differences between the outcomes of students who attend remotely and online versus on-site, yet the existing studies (Lightner & Lightner-Laws, 2016; Szeto, 2014; White, Ramirez, Smith, & Plonowski, 2010) provide evidence for the notion that flexible course delivery options have little to no negative impact on student learning as it results in similar learning outcomes, such as test scores (White et al., 2010), and motivation, needs satisfaction, and perceived success (Butz & Stupnisky, 2016).

2.2. Key challenges of the synchronous hybrid virtual classroom

Apart from the above mentioned benefits, the hybrid virtual classroom also has many challenges, which can be categorized into pedagogical and technological challenges (Raes et al., 2019).

2.2.1. Pedagogical challenges

From the teacher perspective, this type of learning environment requires radical shifts in the teachers' pedagogical methods in order to accommodate to the new technology (Cain, 2015; Ramsey et al., 2016). The synchronous hybrid learning environments are a new kind of setup that highly influence the pedagogic and learning design (Weitze, 2015; Weitze et al., 2013), and thus demand other methods of teaching and different activating learning activities (Bower et al., 2015). This means that the teacher has to adapt his/her teaching approach, but simultaneously has to maintain comparable learning standards (Grant & Cheon, 2007; Lightner & Lightner-Laws, 2016). In addition, because the quality of the teaching is partly dependent on the teacher's competence in using the technology (Bower et al., 2015), the teacher needs to actively learn how to work with the technology and has to get opportunities to try things out and evaluate the outcomes on the basis of evidence (Grant & Cheon, 2007; Weitze et al., 2013).

Another challenge is that the synchronous hybrid learning environment requires more coordination from the teacher (Ørngreen et al., 2015). During the instruction in these new learning settings, the teacher needs to pay attention to both locations and also needs to perform certain operational actions on the teaching and learning platform. Hereby, the instructor has a heavy mental load, which is referred to as hyper-zoom or hyper-focus (Bower et al., 2015; Zydney et al., 2019; Ørngreen et al., 2015).

When looking at the students' perspective in this new learning environment, research comparing the experiences of face-to-face students and remote students, found that these two groups experience the lesson differently in the hybrid synchronous situation (Beatty, 2007, 2010; Szeto, 2014; Zydney et al., 2019). Therefore, it is important to take this into account when preparing the learning experience. What drives the approach of synchronous hybrid learning is the desire to ensure all students are receiving comparable learning experiences regardless of location (Butz et al., 2016). The challenges, however, lie in designing and implementing both pedagogical strategies and technological systems that enact those comparable learning experiences (Cain, Bell, & Cheng, 2016), also referred to as co-presence (Bower et al., 2015). For example, it is imperative that the teacher not only focuses his attention on the remote students and adopts a slower pace with lots of repetition, as these kind of strategies could compromise the class experience of the face-to-face students (Bower et al., 2015; Szeto, 2014; Szeto, 2015).

The study of Olt (2018) specifically aimed to investigate the phenomenon of hybrid virtual learning from the perspective of the remote participant and concluded that the experience of the remote participant can be best explained and understood by the concept of 'ambiguity' in regard to group membership, functionality of technology, and place. Also Huang, Shu, Zhao, and Huang (2017) showed that the remote students still felt excluded from the chief class, because they were physically separated from the F2F class, especially when the remote class encounters technical difficulties without immediate support. Meanwhile, the F2F students felt neglected when the teacher spent much time solving the technical problems.

When implementing synchronous hybrid learning, it gets also more difficult to activate and engage the remote students to the same degree as the students attending face-to-face. In the study of Weitze (2015) both students and teachers state that remote students learned less, were generally more passive and often behaved like they were watching TV and not attending a lesson. One of the reasons for this finding is that teachers give classes based on more monologue-based teaching strategies, which are not well-suited for this kind of learning settings (Weitze, 2015).

In the study of Weitze et al. (2013) remote students indicated that it is difficult to make the teacher aware that they want to answer a question, which makes them frustrated and uninvolved. Therefore, it is important to take this into consideration in the design of the classes and to be aware that remote students need to be more invited into the class activity (Weitze et al., 2013). Further,

remote learners feel a significant sense of distance from their institution. This illuminates the need to address the perceived distance between remote students and their teachers and face-to-face classmates by establishing some sort of connectedness (Ramsey et al., 2016).

Lastly, the synchronous hybrid learning environment demands more self-discipline for students who are following remotely or online (Wiles & Ball, 2013). Since the teacher is not physically present, there is less control of the students' engagement.

2.2.2. Technological challenges

An important question in relation to the pedagogical challenges is what the most effective technologies are for maximizing the social presence of remote students (Zydney et al., 2019). A disadvantage of the learning environment is often the loss of visual and audible cues which normally are observable from the students (Weitze et al., 2013). Because of this loss, it is imperative that the teacher frequently asks questions throughout the lecture and the teacher needs to be attentive to students' input in order to reduce some of the distancing effects (McGovern & Barnes, 2009; Ørngreen et al., 2015). Next to this, students who attend the class remotely should perceive the same audio quality as students who are present F2F since the audio component has been found to be decisive for the success (Bower et al., 2015; Cunningham, 2014). Irvine, Code, and Richards (2013) found that synchronous hybrid tools that mimic face-to-face delivery can help students maintain closer connections with peers. This means that next to audio quality, good video quality and an optimal framing of the teacher is a challenge.

2.3. Engagement of remote students from a self-determination perspective

The potentially low levels of engagement for remote students need to be taken seriously as student engagement is associated with positive learning outcomes (Fredricks, Blumenfeld, & Paris, 2004) and high retention rates (Bote-Lorenzo & Gomez-Sanchez, 2017). Based on previous research, we can state that engagement involves three dimensions, (1) *behavioural* (e.g., focus, attention, participation, effort or involvement), (2) *affective* (e.g. interest, boredom, frustration or enjoyment), and (3) *cognitive* engagement (e.g. learning outcomes, metacognition and self-regulated learning). This three-component model is displayed by the left circle in Fig. 1 and has been used by several researchers in the past (e.g. Dobbins & Denton, 2017; Gobert, Baker, & Wixon, 2015).

In this study, we are particularly interested in unravelling the affective engagement which is the highlighted part of the circle, and its effect on learning achievement, right rectangle in Fig. 1. We further operationalized affective engagement based on the *self-determination theory* (SDT; Deci & Ryan, 1985). SDT has been established as a well-validated and coherent framework for the conceptualization and investigation of motivation in education (e.g. Raes & Schellens, 2015; Vansteenkiste, Sierens, Soenens, Luyckx, & Lens, 2009), and provides theoretical grounds for examining how the social context of a learning environment can influence the motivation for one's learning experience. According to Deci and Ryan's SDT, motivation can be distributed along a continuum from low to high levels of self-determination. The most self-determined style of motivation is intrinsic motivation (IM). As displayed in Fig. 1, it is maintained that IM can be fostered when the context facilitates the satisfaction of three basic needs: i.e. students' need for autonomy, competence, and relatedness (Vansteenkiste et al., 2009). This means that the constructs of perceived need satisfaction are theorized to be positive predictors of self-reported measures of intrinsic motivation (Niemiec & Ryan, 2009). Subsequently IM has found to be a critical factor affecting learning achievement (Giesbers, Rienties, Tempelaar, & Gijselaers, 2013a).

Although there are numerous studies using SDT in various contexts, there are only limited studies that used SDT to examine motivation in technology-mediated learning environments. Yet Butz and Stupnisky (2017) support the use of SDT for research on synchronous hybrid learning environments as the SDT-based construct of relatedness is closely related to the social presence theory of Short, Williams, and Christie (1976) which is one of the most common models used to examine connections among individuals in technology-mediated learning. Butz and Stupnisky (2017) indicated that online synchronous hybrid students reported significantly lower levels of relatedness than their on-campus counterparts which corroborated their previous study (Butz, Stupnisky, Peterson, & Majerus, 2014). Other research using SDT found that students' perceived satisfaction in terms of autonomy, relatedness, and competence is associated with greater levels of intrinsic motivation in online programs (Chen & Jang, 2010). In line with this, Roca and

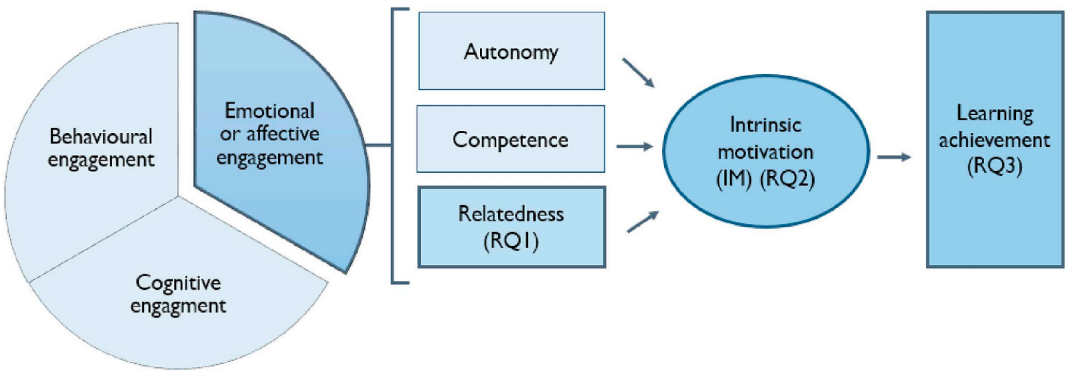

Fig. 1. Dimensions of student engagement within taught contexts (Dobbins & Denton, 2017) and affective engagement perceived from the self-determination theory (Deci & Ryan, 1985). Variables under study are highlighted.

Gagné (2008) determined that perceived relatedness in online courses positively predicts learners' intention to continue their program. Furthermore, Giesbers, Rienties, Tempelaar, and Gijselaers (2013b) showed that higher levels of relatedness are associated with intrinsic motivation in synchronous online tutoring sessions. Another study from the same authors (Giesbers et al. (2013a) found that intrinsic motivation in turn is positively correlated with final exam scores.

2.4. Effect of quizzes and polls during lectures

Studies reveal that students in traditional, non-interactive lectures are 1.5 times more likely to fail than students that are cognitively activated and that the longer a lecture takes, the less information is retained (Freeman et al., 2014). This is because new information pushes back previous information which is not yet committed to long-term memory and it has been found that learners have limited capacity to focus on one topic for a long time as the average attention span is between 10 and 15 min (Bunce, Flens, & Neiles, 2010). Wilson and Korn (2007) did a literature review to evaluate this claim, including several types of studies using note taking, observations of students during lectures, self-reports, as well as studies using physiological measures of attention. They found that the research on which this estimate is based, provides little support for the belief that students' attention declines after 10–15 min. They suggest that teachers should take into account individual differences in student attention when lecturing and develop ways to maintain student interest in the classroom.

One specific tool that can be used to monitor student engagement within lectures is launching quizzes or polls, a feature which is included in most web-conferencing platforms (Bower et al., 2015). With this tool teachers can easily collect students' votes on multiple choice questions or polls through the platform, facilitating dynamic formative assessments and opinion survey during lectures. An extensive literature review by Kay and LeSage (2009) shows that quizzes and polls have proven to be an effective educational tool as students attended more classes, paid more attention, and were more engaged. Similarly, research done by Dobbins and Denton (2017) indicates that students were unequivocal that the use of quizzes and polls presented a good way for them to become more involved and interact within lectures. They also reveal that this solution is particularly beneficial for students who are rather shy and would not usually vocally participate during lectures in front of everyone, fearing other students would perceive their question as 'stupid'. A recent longitudinal study monitoring both students' initial perceptions and the perceptions after experiencing quizzes during lectures revealed that students had positive expectations toward using quizzes and polls during lectures and that technology acceptance (including perceived usefulness and attitudes towards quizzes and polls) was even higher after experiencing the technology (Raes et al., 2019; Raes & Depaepe, 2019). Moreover, the results counter the possible novelty effect as no decrease in technology acceptance was found. Students especially stress the beneficial cognitive and affective effects for learning new course content; a student stated for example the following: “Lectures become much more interactive when quizzes are used. I especially like it at the end of a session as recapitulation of the course content.” (Raes et al., 2019, p. 4).

3. Related research and related technologies

As stated in the theoretical framework, the effectiveness of the learning activity in the synchronous hybrid virtual classroom is directly influenced by the pedagogical and technological design choices. In this section, first we review related work and other existing solutions; second, limitations of previous research and existing solutions are outlined, and third, the current study and technological solution under investigation is described in detail.

3.1. Related research and existing solutions

The first study on synchronous hybrid learning date from 2003, a qualitative case study aiming to observe the quantity and quality of human interaction between the instructor, the face-to-face students, and the remote students in a blended learning course (Rasmussen, 2003). Also the work of Beatty (2007, 2010) was pioneering in the development, and evaluation of the HyFlex course design model for blended learning environments. The most studies date from a later period, i.e. published between 2013 and 2019. Most of the studies are case studies using mixed-methods or qualitative analysis, yet empirical studies are limited (see Raes et al., 2019 for the complete literature review). Raes et al. (2019) only found five studies taken a comparative approach to study the effectiveness between different modes of delivery. Only one experimental study was found. This study was set up from a pretest-posttest experimental design with random assignment using a convergent parallel mixed methods approach (Butz & Stupnisky, 2017).

Previous research on synchronous hybrid learning used different video or web-conferencing platforms which have recently emerged to facilitate synchronous course delivery and share similar features, such as Adobe Connect™ (formerly Macromedia Breeze; Adobe Systems), Blackboard Collaborate™ (formerly Wimba Classroom and Elluminate Live!; Blackboard), WolfVision and WebEx Collaboration Suite (Cisco Systems). Bower and Hedberg (2010) noted that in general such these platforms entails the following features: i.e. presentation delivery, screen-sharing, webcam, text-chat, whiteboard, file upload/download, polling, attendee list, and notepad.

3.2. Limitations of previous research and solutions

As described in the section on technological challenges, the loss of visual and audible cues often remain a struggle in previous studies. Also the teacher is often forced in a less naturally teaching position as teachers need to teach seated, wearing a good quality headset with a built in microphone and using the webcam on their computer or laptop if they wish to stream a video. In addition, the

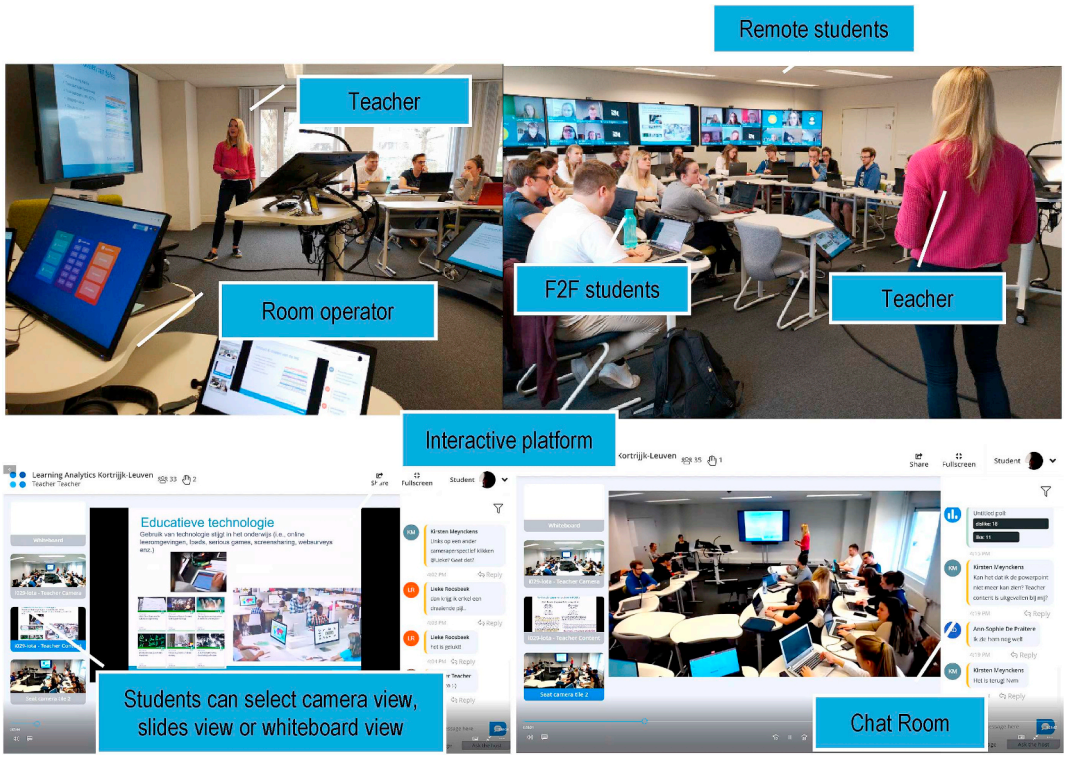

Fig. 2. Upper pictures display the hybrid virtual classroom including both F2F and remote individual students. Lower pictures display the platform visible for the students.

technology can be an imposition for the teacher and the F2F students, for instance if they need to be conscious of the orientation/positioning of cameras or are required to speak into a microphone interrupting conversational flow (Bower et al., 2015; Cunningham, 2014; Zydney et al., 2019). It has also to be noted that in most innovative learning environments, the technology is very visible, for example, the camera is visible and it is apparent when it is recording and streaming to remote students. This can make teachers very aware of their teaching performance and can cause them to act differently (Nortvig, 2013).

3.3. Current solution in relation previous solutions

The hybrid virtual classroom under investigation has recently designed in the context of the TECOL project (See (Raes et al., 2019) and the LECTURE+ project, a research and development project in collaboration between academia and industry aiming to build a promising solution for synchronous hybrid learning delivery supporting the idea that students and teachers interacting from different locations will feel as though they are in the same room. To achieve this goal, the design of the *hybrid virtual classroom* not only focused on the software to connect students and the teacher. Furthermore, there is a strong focus on the design of the physic learning space to meet the challenge of offering all students comparable learning experiences regardless of their location as the challenge lies in designing and implementing both pedagogical strategies and technological systems that enact those comparable learning experiences (Cain et al., 2016). As visible on Fig. 2, on the one hand the teacher and F2F students see the remote students as part of the classroom as they are displayed as if they are an additional row in the audience. On the other hand, the remote students see the teacher from the camera viewpoint where they are projected on meaning that the teacher is really talking and looking at them. The teacher is free to move around in the room seeing all his/her students which supports educational flow which is not always the case when using other systems supporting synchronous online learning in which the teacher often has to sit behind his/her laptop or does not always have a view on all remote students (at the same time). Another difference with other existing solutions is the hardware lightweight and ease of use of the set-up. In this set-up only one room operator is needed or no operator is needed if the teacher has some experience in this setting. This is a significant difference compared to other solutions which in some cases need up to six room operators who have both technical roles (directing, producing, camera steering, colour correcting, enabling the debate mode, lecture capturing, …) and pedagogical support roles (moderating student content such as silent questions and screen sharing, measuring student participation for feedback and evaluation). This makes such solution economically unviable for the average educational institution.

All students have access to the same interactive platform shown in Fig. 2, allowing them to participate in the course, either on-site or from a remote location. The platform gives access to the sources the teacher is using during his or her lecture (e.g. power point slides or annotations made on the digital whiteboard), facilitates launching quizzes or polls and is equipped with a chat room which gives students the possibility to chat with each other or with the teacher during the lecture. Lectures in the hybrid virtual classroom

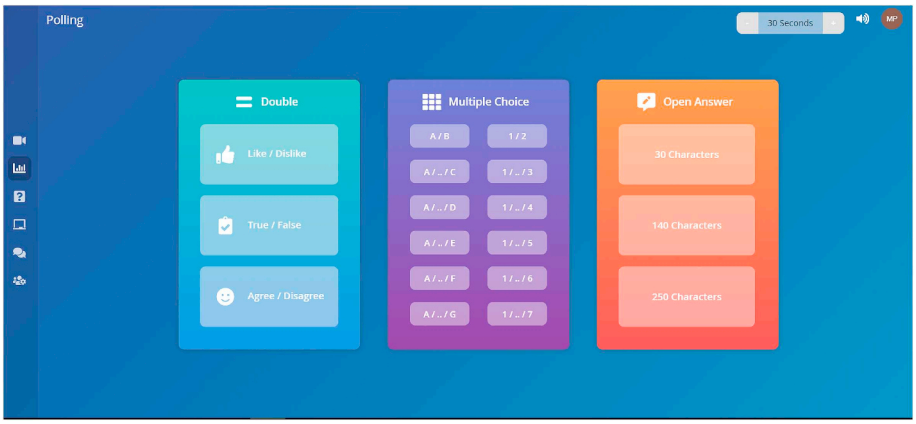

Fig. 3. The project platform weConnect for launching interactive quizzes and polls in the hybrid virtual classroom.

are so far always assisted by a room controller who follows up on the chat, can launch the quiz or poll and can mute or unmute remote students, but some teachers already indicated that it might be feasible without. As visualized in Fig. 3, the platform gives the teacher or the room controller the opportunity to launch quizzes and polls on the fly during lectures. Once a quiz or poll is launched, the question immediately pops up on students' interfaces. Subsequently, the teacher or room controller presents the results to students on the teacher dashboard which is integrated within the project platform.

This hybrid virtual classroom is operational since October 2018 and no educational research has been published on the use and effectiveness of learning and instruction in the hybrid virtual classroom. Moreover, this research study meets the needs for more empirical research. Aside from the studies mentioned in the theoretical framework, however, explicit tests of SDT in hybrid learning environments are still rare and a limitation of the existing research is that no previous studies have systematically investigated need satisfaction, intrinsic motivation (IM) and learning achievement in the hybrid virtual classroom. Next to this, previous studies have often been conducted in various contexts with a lot of confounding variables, e.g. different teachers and different students groups. Also, most research is based on retrospective self-report and to the best of our knowledge, the effect of quizzes has not been systematically investigated in the context of the hybrid virtual classroom.

4. Methodology

4.1. Research focus, research questions and hypotheses

This study aims to fill this research gap by systematically investigating relatedness, IM and learning achievement in the hybrid virtual classroom through an experimental within-subjects design (see Fig. 4) comparing four learning settings. The educational setting depends on whether students were physically present and thus attended the lecture face-to-face ("F2F") or remotely ("virtual"), and on whether the setting was the same for all students ("pure") or mixed ("hybrid"). Following that line of thought the

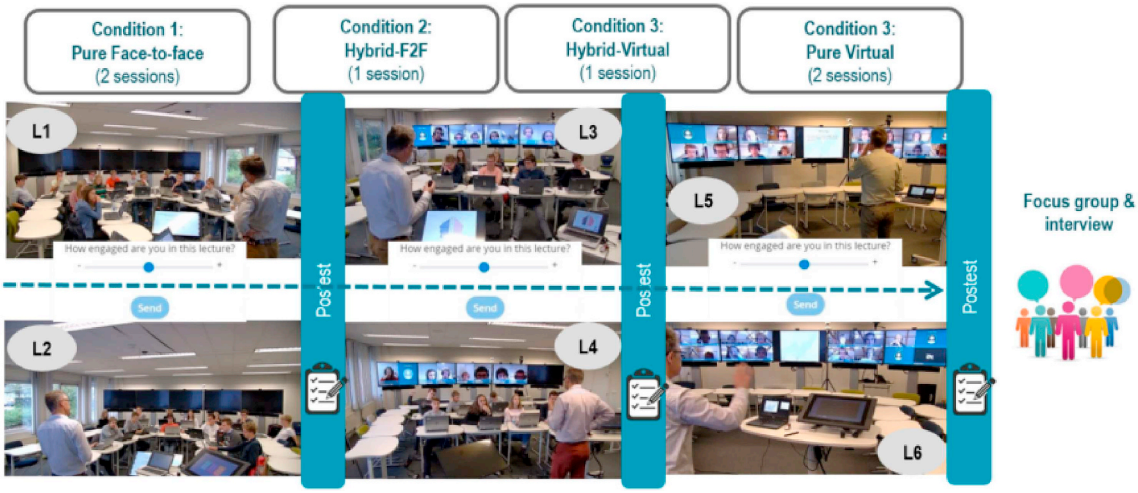

Fig. 4. Experimental within-subjects design in which one teacher and 14 students were followed during six lectures. The numbers in L1, L2, etc. indicates the chronological order of each lecture.

following conditions can be distinguished:

- The pure F2F setting, where all students are physically present in the classroom
- The hybrid-F2F setting: this is the hybrid setting experienced by students that are physically present in the classroom, on the same location as the teacher
- The hybrid-virtual setting: this is the hybrid setting experienced by students that attend the lecture virtually from a remote setting
- The pure virtual setting, where all students attend the lecture remotely

Following research questions and corresponding hypotheses are put forth based on the characteristics of the learning settings and based on previous research on SDT and previous research on the effect of quizzes on engagement:

RQ1. How is the basic need of relatedness experienced by students in the four different learning settings?

H1a. Virtual students have a lower experienced relatedness to the teacher compared to F2F students, no matter whether it is a pure or hybrid setting.

H1b. Virtual students have a lower experienced relatedness to peers compared to F2F students, particularly in the hybrid setting.

RQ2. What is the experienced IM of students in the four different learning settings?

H2. Virtual students' IM is lower than F2F students' IM, particularly in the hybrid setting.

RQ3. To what extent is IM positively related with students' learning achievement?

H3. IM is positively correlated with students' learning achievement.

RQ4. To what extent does IM change over time during the lecture and what is the effect of quizzes on students' IM?

H4. Students' IM decreases over time.

H5. Quizzes have a positive impact on students' IM.

RQ5. What is the perceived usefulness and the attitude towards quizzes across the four different learning settings and how did the teacher and students experience the hybrid virtual classroom regarding usability?

As there is no previous research systematically investigating the effect of quizzes in the context of the hybrid virtual classroom, no hypothesis is formulated.

4.2. Experimental design, participants & procedure

To solve our research questions, an within-subjects experimental design has been set up. The study design has been reviewed and approved by the social and societal ethics committee of KU Leuven. For this experiment, we collaborated with a teacher of secondary education and his 14 students of Grade 12 (average age of 17) following the course 'Economics'. Prior to the experiment, the third author visited the school to informed all students orally about the context and the main objectives of the study. Students could voluntarily participate in the study by signing an informed consent. The form informed participants that they were going to be videotaped, that data from self-reports and from the learning platform was going to be collected and that all data was going to be processed anonymously. Students could refuse to participate or stop at any moment, even when students had already given their consent. All students agreed upon the informed consent which resulted in 14 participants, four of them were girls and ten were boys. The within-subject design consisted of six lectures of 60 min (one per week during six consecutive weeks) which were given by the economics teacher who made use of the *hybrid virtual classroom* infrastructure at our university. As displayed in Fig. 4, during Lecture 1 and Lecture 2, all students came to the university and attended the course F2F. In Lecture 3 and Lecture 4, the students participated in the hybrid setting, the student group was split up and half of the students were attending the course virtually and half of the students were attending the course F2F. The groups were swapped after Lecture 3, so all students could experience both perspectives in the hybrid classroom. In Lecture 5 and 6 all students attended the course virtually, whereas the teacher was present in the *hybrid virtual classroom*. As a result, four conditions can be distinguished: a pure face-to-face condition (F2F), a hybrid session followed face-to-face (hybrid-F2F), a hybrid session followed virtually (hybrid-virtual) and a pure virtual condition (virtual).

To control for contextual variation, all courses were given by the same teacher and the third author assisted this teacher in preparing his lectures to make sure that each lecture followed the same pedagogical script. The lectures lasted approximately 60 min, Lecture 5 lasted 12 min longer, Lecture 6 lasted 10 min less. Each lecture started with an interactive poll related to the content of the lecture. Each lecture ended with a quiz which served as a formative assessment of the understanding of the giving content, and included five multiple choice questions. As further explained, the quiz scores are used in this study as a measure for learning achievement. Between the poll and the quiz, the teacher taught his lecture supported by means of presentation software and he frequently asked oral questions to his students.

4.3. Data collection and measures

Data have been collected from a mixed-methods approach which implies the combination of quantitative and qualitative research

Table 1
Sample items for the different variables included in the post-interventions survey and the accompanying reliability scores.

Variables	Sample items	Cronbach's alpha
Relatedness (3 items)	I felt really distant to the teacher (R)	NA
- Relatedness towards teacher – (1 item)	I felt close to my classmates	Survey 1: α = .47
- Relatedness towards peers (2 items)	I felt as part of the class	Survey 2: α = .93
		Survey 3: α = .95
		Survey 4: α = .91
Intrinsic motivation (4 items)	I thought this was a boring activity.(R)	Survey 1: α = .82
	This activity did not hold my attention at all.(R)	Survey 2: α = .90
	I would describe this activity as very interesting.	Survey 3: α = .95
	I thought this activity was quite enjoyable.	Survey 4: α = .81
Perceived Usefulness of quizzes (3 items)	Quizzes and polls improved the quality of my learning process.	Survey 1: α = .75
	Quizzes and polls improved the understanding of the content.	Survey 2: α = .87
	Quizzes and polls make it more easy to cope with the learning material	Survey 3: α = .94
		Survey 4: α = .84
Attitudes towards of quizzes (3 items)	Quizzes and polls make the course more fun	Survey 1: α = .88
	Quizzes and polls make the course more interesting	Survey 2: α = .85
	Quizzes and polls keep lessons exiting	Survey 3: α = .91
		Survey 4: α = .85

methods (Cohen, Manion, & Morrison, 2011). This approach strengthens the inferences in the analysis of relatedness and intrinsic motivation, which are complex constructs to measure.

First, quantitative data have been collected through surveys to obtain the measures of the variables presented in Table 1. It was a short survey of 2 pages which students completed on paper in five to 10 min. A post-intervention survey has been administered four times: (1) after the two F2F sessions had taken place, (2) after the first hybrid session in which half of the students attended virtually and the other half F2F, (3) after the second hybrid session, and (4) after the two virtual sessions had taken place. To answer RQ1 and RQ2, the post-intervention survey was based on the Intrinsic Motivation Inventory (IMI) (Deci &, Ryan, 1985) including Likert-scale questions using six-point agreement levels from 1 (strongly disagree) to 6 (strongly agree). The original instrument assesses participants' interest/enjoyment, perceived competence, effort, value/usefulness, felt pressure and tension, perceived choice, and experience of relatedness during a certain activity, thus yielding seven subscales. As indicated on the selfdeterminationtheory.org website, the subscale experience of relatedness has been added most recently to the IMI and the validity of this subscale has yet to be established. In this study, we will only report on the relatedness scores and the scores for the interest/enjoyment subscale which is considered the self-report measure of IM. Yet, it has to be mentioned that the original subscale does not specify the relatedness towards a specific person or group of persons. In this study the perceived relatedness is operationalized as relatedness towards peers and relatedness towards the teacher.

Next to these SDT scales, the surveys included two subscales borrowed from the Technology Acceptance Model (TAM) (Davis, 1989) to measure students' perceived usefulness of quizzes and their attitudes towards quizzes during the lectures in the different learning settings (see RQ5). Table 1 presents sample items for the different variables included in the post-interventions survey and the accompanying reliability scores. The Cronbach's alphas regarding the different subscales administered through four measurements indicate that the scales were reliable, expect for one, i.e. relatedness towards peers in survey 1. It has to be noted that the small size of the dataset ($N = 14$) puts certain limits on the accuracy with which Cronbach's alpha can be estimated. In addition, the small number of items included in the questionnaires is more likely to give rise to lower alpha-values.

To answer RQ3 and investigate the relation between IM and students' learning achievement, this latter variable is based on students' quiz scores. At the end of each lecture a quiz was launched which counted as formative assessment of the understanding of the giving content, and included five multiple choice questions per quiz. This resulted in a score out of 5 per student, per lecture. As the post-intervention surveys were only administered after two F2F lectures and after two virtual lectures, whereas the quizzes were held each lecture, the temporal assessment of IM (described in the next paragraph) has been used to test RQ3.

To answer RQ4 aiming to examine to what extent IM changes over time during the lecture and to study the effect of quizzes on students' IM, the post-intervention survey data could not be used as they are a snapshot articulation of engagement rather than an examination of how emotion unfolds in an interactive context (Scherer, 2005). To capture possible evolutions and test the effect of quizzes on students' IM, a temporal assessment of IM has been realized by means of an engagement pop-up. This pop-up contained one question, i.e. *"How engaged are you now?"*, which students could answer on a slider allowing for continuous values between 0 and 2. A value of 2 represents a very engaged state, a value of 1 represents a neutral state and a value of 0 a very disengaged state. Students got this pop-up during all lectures at random intervals between 5 and 12 min. By means of these data, we can get insight in the fluctuations within students over time.

To get additional insights into our quantitative results regarding the five research questions and regarding the fifth research question more particularly, also qualitative data have been obtained through open-ended questions in the post-tests, a semi-structured interview with the teacher organized after the final lecture, and a semi-structured focus group with all students, one month after the last lecture. This method is described as explanatory sequential design (Creswell & Plano Clark, 2010), wherein individual interviews and/or focus groups are used to explain the results obtained from quantitative surveys. The interview with the teacher lasted about 20 min. The focus group with the students was organized during one of the regular lectures at their school, the session

lasted 40 min. The focus group interview was structured by means of a PowerPoint presentation and the polling software Mentimeter. First students were asked about the expectations regarding the results of the study they were involved in by means of a poll. Next, the results of the quantitative data were presented to the students. These two steps were followed by a discussion led by questions as 'Did you expect these results?', 'Do you have possible explanations for this finding' … After presenting and discussion the results, some extra polls were presented, for example questioning their preference regarding the use of quizzes during lectures. Three of the authors and the participating teacher in this research were present during the focus group interview.

4.4. Data analysis

The quantitative data obtained through the post-intervention surveys and the temporal engagement pop-ups are analysed by using a two-level model, because we have a hierarchical data structure, with measurements (Level 1) nested within students (Level 2). By using such a two-level model explicitly modelling the students' effects on the scores as a random effect, we deal with the non-independence of the scores coming from the same student, thereby avoiding flawed statistical inferences. To study differences between educational settings, we include the setting as a categorical predictor in the model.

The dependent variables obtained through post-intervention surveys are students' relatedness to peers, relatedness to the teacher, intrinsic motivation, perceived usefulness of quizzes, and attitude towards quizzes (RQ1, 2 and 5). The same analyses are performed for the different dependent variables. Therefore, the data analysis is described in a generic way, where Y_j can either represent relatedness, IM or the perceived usefulness and attitudes towards quizzes. Each dependent variable Y_j is standardized prior to analysis, bringing its mean to 0 and its variancefo to 1. By standardizing, we can compare the regression coefficients over the different outcome variables. First, for all dependent variables, a Type III F-test is performed, to verify whether means differ across conditions. Next, we fitted a model without intercept, such that the obtained regression coefficients β_i can be interpreted as the expected standardized scores in each of the four conditions. The *p*-value corresponding to a regression coefficient tests whether the expected value in a certain condition differs from zero. Pairwise comparisons are performed as we are mainly interested in differences between conditions. *P*-values were corrected for multiple testing according to Holm's method.

Additional multilevel analyses are done to study the effect of students' intrinsic motivation on students' learning achievement (RQ3). Student' IM is included as a predictor with a fixed effect and is standardized prior to analysis. In that way, the regression coefficient βi can be interpreted as a standardized regression coefficient.

Finally, also the quantitative data obtained through the temporal engagement pop-up allowing to study the evolution of students' engagement over time and the effect of quizzes (RQ4) are analysed using multilevel modelling. Yet, in this analysis, the time elapsed since the start of the lecture is included as a predictor with a linear fixed effect. In order not to overcomplicate the model and given the rather small sample size, it is assumed that the linear time trend is the same across subjects. Furthermore, a dummy variable is included to indicate whether a quiz is going on at a certain moment (1) or not (0). To control for the different conditions, the educational setting is still included as a predictor.

The software package R is used to perform the data analysis. To be more precise, the lme4-package and its lmer() function are employed, in which estimates of the mixed effects models are chosen to optimize the restricted maximum likelihood (REML) criterion.

Qualitative data of both the teacher interview and the focus group with students were audio recorded and fully transcribed afterwards. Based on the transcriptions, content analysis (Cohen et al., 2011) was used to generate common experiences and valuable feedback regarding their experience of learning and teaching in the hybrid virtual classroom with specific attention to the five research questions.

5. Results

5.1. RQ 1: How is the basic need of relatedness experienced by students in the four different learning settings?

Table 2 presents the results of the multilevel analyses including the regression coefficients and the corresponding standard errors

Table 2
Comparison of relatedness, intrinsic motivation, learning achievement, usefulness and attitudes towards quizzes in the different learning settings.

Dependent variables	Educational setting as independent variable							
	Pure F2F		Hybrid-F2F		Hybrid-Virtual		Pure Virtual	
	β_i	(SE)	β_i	(SE)	β_i	(SE)	β_i	(SE)
Relatedness towards teacher	0,61	(0,18)	0,94	(0,17)	−0,75	(0,17)	−0,75	(0,17)
Relatedness towards peers	0,87	(0,21)	0,14	(0,21)	−0,85	(0,21)	−0,15	(0,22)
Intrinsic motivation (post)	0,27	(0,26)	0,09	(0,27)	−0,48	(0,26)	0,12	(0,26)
Intrinsic motivation (temporal pop-up)	0,48	(0,16)	0,17	(0,16)	−0,28	(0,17)	0,14	(0,16)
Learning achievement	0,03	(0,27)	0,13	(0,27)	−0,41	(0,27)	0,24	(0,27)
Perceived Usefulness of quizzes	−0,13	(0,27)	−0,02	(0,27)	−0,08	(0,27)	0,23	(0,27)
Attitudes towards of quizzes	−0,01	(0,27)	−0,03	(0,25)	−0,24	(0,25)	0,33	(0,25)

for the different dependent variables included in our study. Regarding the basic need satisfaction of relatedness, when analysing the relatedness to the teacher, a significant main effect for the educational setting was found, $F(3,51) = 26.5$, $p < .001$. The highest relatedness to the teacher was reported in the hybrid-F2F setting ($\beta_i = 0{,}94$) and in the pure F2F setting ($\beta_i = 0.61$). These two conditions did not significantly differ from each other ($p = .23$). The relatedness to the teacher in these conditions was significantly higher (all pairwise comparisons resulted in $p < .001$) than in the hybrid-virtual ($\beta_i = -0.75$) and the pure virtual condition ($\beta_i = -0.75$), which were found to be similar in terms of relatedness to the teacher. This means that regarding relatedness towards the teacher, our Hypothesis 1a is confirmed stating that students' experienced relatedness towards the teacher is higher if students participate F2F in the course, either in the pure F2F setting or in the hybrid-F2F setting. Students' experienced relatedness towards the teacher is lower if students participate remotely in the course in the pure virtual setting or in the hybrid setting.

With regard to relatedness to peers, also a significant effect for the educational setting was found $F(3,51) = 11.2, p < .001$. Yet, the pairwise comparisons resulted in different findings as compared to the relatedness towards the teacher. It was found that students' relatedness to peers was the highest in the pure F2F setting ($\beta_i = 0.87$). In this setting, the relatedness to peers was significantly higher than for the hybrid-F2F setting ($p = .02$; $\beta_i = 0.14$) and the pure virtual setting ($p = .002$; $\beta_i = -0.15$). The relatedness to peers in these two settings did not significantly differ from each other, but were significantly higher ($\beta_i = -0.85$) than the hybrid-virtual setting (with $p = .002$ when comparing to the hybrid-F2F setting and $p = .02$ when comparing to the pure virtual setting), which turned out to be the worst condition in terms of relatedness to peers. This means that Hypothesis 1b could be confirmed regarding relatedness towards peers.

5.2. RQ 2: What is the experienced intrinsic motivation of students in the four different learning settings?

Regarding intrinsic motivation, there was no significant main effect for the educational setting, $F(3,51) = 1.55$, $p = .21$. However, when performing pairwise comparisons, it was found that the pure F2F setting yielded the highest scores in terms of IM ($\beta_i = 0{,}27$), and that these scores were significantly higher ($p = .02$) than for the hybrid-virtual setting ($\beta_i = -0{,}48$), where students were least motivated. This means that Hypothesis 2, stating that virtual students' IM will be lower than F2F students' IM, particularly in the hybrid setting, could be confirmed.

These quantitative results are in line with the qualitative results as both the teacher and the students mentioned that the hybrid sessions were the most puzzling to teach in on the one hand and to learn in on the other hand. More specific, the teacher expressed that it was not always easy to divide the attention between the F2F students and the remote students.

On the students' side, a number of technical and pedagogical obstacles regarding the hybrid virtual classroom were mentioned. One of these obstacles was that the F2F students had to use the microphone when reacting orally to make sure that the virtual students could hear them. They expressed that this did not feel natural. A student also indicated that he – as F2F student - often turned his head during the lesson to see the faces of his peers on the screens in the back. Another student also explicitly mentioned to feel a distance from their peers and the teacher in the remote setting and expressed that it felt like watching a movie without feeling real contact. This student mentioned that it was boring and weird to be separated from the others in the hybrid-virtual setting. Students also indicated that attending the lecture virtually was more tiring and that this kind of learning is only suitable for certain courses with a maximum of 2 h a day. Yet, students mentioned that the available chat box might have helped in establishing some sort of connectedness with their peers. Notwithstanding these obstacles, most students did also mention that they experienced the remote learning positively and stressed that they were surprised about the audio and video quality and students found it easy to use. Both the technical quality and the ease of use of the system supported the interaction between the teacher and the remote students. Students expressed to see the possibilities of the new technology creating much more flexibility.

This positive evaluation was also shared by the teacher. During the final interview, conducted at the end of the experiment, the teacher expressed his enthusiasm about this educational experiment and mentioned that the experience exceeded his expectations. He stated this as following:

> "I thought that teaching to virtual students would have been very artificial and weird, but this was not at all the case. I had the feeling that my students were very close to me and I could see their faces and expression even better than in a traditional F2F classroom; … I could easily interact with them as I do in a normal class setting and I had the feeling my students were very attentive."

The teacher also stated that the educational setting had not influenced his style of teaching. He mentioned that he could easily start a dialogue and stated that the students who were most interacting were the same as in normal F2F classes. Yet, he expressed that he missed his traditional white board. Although there is a white board function in the platform, the teacher did not use it because he was not used to it and was afraid that it would not work.

5.3. RQ 3: To what extent is IM positively correlated with students' learning achievement?

Results show that there is a significant effect of students' IM on students' learning achievement ($\beta_i = 0.29$; $p = .001$), meaning that our hypothesis could be confirmed. This shows that the more engaged students are, the more likely to obtain better learning outcomes on the formative assessments conducted through quizzes.

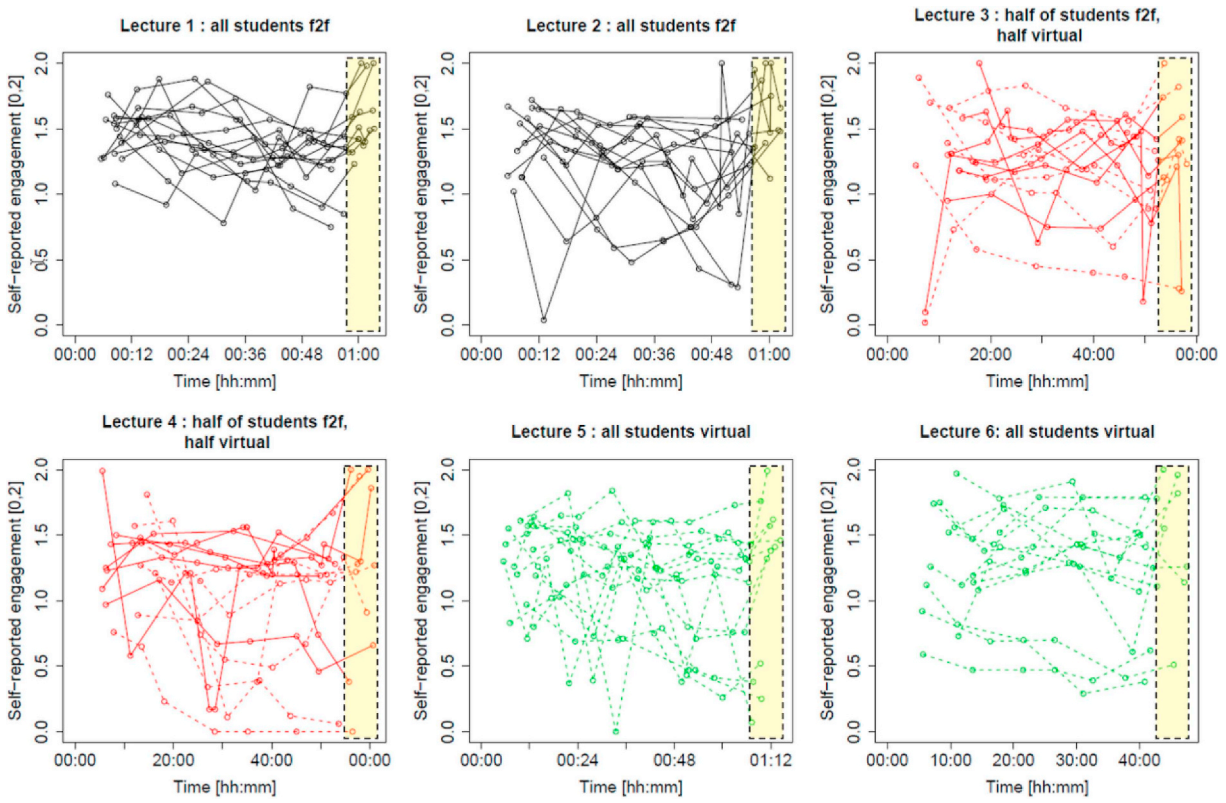

Fig. 5. Results of the engagement pop-up. Solid lines apply to students who were attending the lecture F2F; dashed lines apply to students attending the lecture remotely. The yellow rectangle indicates the time quizzes were launched. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

5.4. RQ 4: To what extent does IM change over time during the lecture and what is the effect of quizzes on students' IM?

Fig. 5 displays the results of the temporal engagement pop-up which students responded to during the six lectures. Solid lines apply to students who were attending the lecture F2F; dashed lines apply to students who were attending the lecture remotely. The periods in which the quizzes were launched are indicated by the yellow rectangle. Results of the multilevel analysis indicate that there is a negative effect of time - elapsed since the start of the lecture - on students' IM ($\beta_i = -0{,}17; p < .01$) confirming Hypothesis 4 (i.e. Students' IM will decrease over time). Furthermore, students' IM was found to be higher during quiz moments than during other moments of the lecture ($\beta_i = 0{,}28; p < .001$). This finding endorses Hypothesis 5, stating that quizzes positively affects students' IM.

5.5. RQ 5: What is the perceived usefulness and attitudes towards quizzes in the four different learning settings and how did the teacher and students experience the hybrid virtual classroom regarding usability?

Regarding the perceived usefulness of quizzes and the attitude towards using quizzes during lectures, the results indicate that all students experienced the quizzes positively (all scores were above 4 out of 6). *F*-test analyses indicated that there was no significant main effect for the educational setting both regarding perceived usefulness ($F(3,52) = 0.36$, $p = .78$) and attitudes ($F(3,52) = 0.77$, $p = .52$). Pairwise comparisons did not reveal significant differences between settings. This means that students equally benefit from quizzes during lectures, no matter in which setting they are.

Regarding the usability of the hybrid virtual classroom, we can confirm that during the experiment, no major technological problems occurred thanks to a good preparation and guidance during the sessions. As the system is still relatively new, support was required to start up the lecture, and audio quality had to be checked at the start of each lecture. In addition, technical assistance was required for the purpose of the data collection to make the video-recordings and to collect data from the learner platform.

Based on the observations during the sessions and based on the focus group and interview with the teacher, we can state that for students, it was relatively straightforward to use the student interface. Students indicated in the focus group that they could use the different functionalities that the platform offers in an intuitive way. Only some technical assistance was required before the start of the lecture to make sure students could log in to the system (filling in the correct user name and password) and to make sure remote students' headsets were working properly.

For the teacher, it was more difficult to simultaneously focus on his teaching job and launching interactive quizzes. Although launching quizzes with the platform is easy and intuitive, a room controller provided support by launching the quizzes in his place.

The teacher expressed that this support was crucial to make him feel comfortable and relaxed during teaching in this new environment. The teacher experienced the use of quizzes for the first time, but was very enthusiastic about this technology and expressed that he would like to use this in his future lectures. Also the students stated during the focus group that they really appreciated the quizzes and half of them indicated that they would prefer that they would implemented more frequently during the lectures. We are convinced that as teachers get more experienced in teaching in the hybrid virtual classroom, they will also be able to launch quizzes or other interactive elements themselves. Finally, as already stated under research question 2, the teacher was excited about the system in general as he stated that he was surprised about the ease with which he could interact with his students.

6. Discussion & implications for theory and practice

To deal with current shifts in education, the TECOL and LECTURE+ project invested in the design, research and development of a hybrid virtual classroom in collaboration with industry partners. This hybrid virtual classroom is innovative compared to previous video- and web-conferencing platforms facilitating synchronous hybrid course delivery to face-to-face and remote students for the following reasons. The system not only includes improved software to connect students and the teacher and to make spontaneous interaction possible, but also redesigned the physical learning space or classroom in a way to meet the challenge of offering all students comparable learning experiences regardless of their location. Special attention has also been paid to the hardware lightweight and ease of use of the set-up from the perspective of the teacher, the students and the room operator. In the hybrid virtual classroom, four different learning settings can be distinguished from the students' perspective: (1) the pure F2F setting in which all students are physically present in the classroom, (2) the hybrid-F2F setting experienced by students that are physically present in the classroom, on the same location as the teacher; (3) the hybrid-virtual setting experienced by students that attend the lecture virtually from a remote setting, and (4) the pure virtual setting in which all students attend the lecture remotely. This study aimed to investigate to what extent this hybrid virtual classroom could satisfy the need for relatedness (RQ1) and the intrinsic motivation (RQ2) of students in the four different learning settings. Based on previous literature, it was hypothesized that virtual students would have a lower experienced relatedness and a lower experienced intrinsic motivation (IM) compared to F2F students, particularly in the hybrid setting. This study also aimed to confirm the positive relation between IM and learning achievement (RQ3). Next, the evolution of students' IM over time has been studied in combination with the effect of launching quizzes on students' IM (RQ4). Finally, also the perceived usefulness and the attitude towards quizzes have been studied across the four different learning settings (RQ5). These five research questions have been systematically investigated through an experimental within-subjects design based on a mixed methods approach.

Our results for RQ1 indicate that students' experienced relatedness towards the teacher is lower if students participate remotely in the course in the pure virtual setting or in the hybrid setting. With regard to the relatedness to peers, the hybrid-virtual setting is found to be the worst setting regarding experienced relatedness to peers. This finding is in line with the results of RQ2 showing that students were least motivated when participating remotely in the hybrid setting. When all students participate virtually, the intrinsic motivation is higher. The qualitative results are in line with this finding; a student for example mentioned that is was boring and weird to be separated from the others in the hybrid-virtual setting. Our results confirm previous findings (Huang et al., 2017; Ramsey et al., 2016) showing that remote learners indeed feel a significant sense of distance between remote students and their teachers and face-to-face classmates and the study of Olt (2018) who concluded that the experience of the remote participant can be best explained and understood by the concept of 'ambiguity' in regard to group membership, functionality of technology, and place. Our findings are also in line with the study of Butz and Stupnisky (2017) who indicated that online synchronous hybrid students reported significantly lower levels of relatedness than their on-campus counterparts. The finding that students' engagement is especially low in the hybrid setting can probably be explained by the Social Identity Theory (Tajfel, 1979), stating that the group which people belong to is an important source of social identity, a sense of belonging to the social world. If all students participate virtually, students probably feel more belonging to the same group, whereas in the hybrid setting, two separate groups can be distinguished. Although the environment tries to create a comparable experience, students still perceive differences which can lead to in-group and out-group feelings. In this setting the hybrid-remote students are then the out-group and as they participate individually, it can even be questioned if they even feel belonging to a group at all.

These results also confirm the self-determination theory stating that when students' relatedness increases, IM in learning is better supported (Giesbers et al., 2013b; Roca & Gagné, 2008) and is in line with other research using SDT. These studies state that students' perceived satisfaction in terms of autonomy, relatedness, and competence is associated with greater levels of intrinsic motivation in online programs (Chen & Jang, 2010).

In addition to previous work, our study shows that especially the relatedness towards peers is related to IM and based on this finding we would suggest to conduct further research to investigate how relatedness should be measured in further research. We do agree with Butz and Stupnisky (2017) that the use of SDT for research on synchronous hybrid learning environments is appropriate, yet, as the subscale experience of relatedness has been added most recently to the IMI and the validity of this subscale has yet to be established, more research is needed to be able to measure the experience of relatedness in a more elaborated way. We would suggest to include related theories and models used to examine connections among individuals in technology-mediated learning, e.g. the social presence theory of Short et al. (1976) and the theory of presence (Witmer, Jerome, & Singer, 2005). This research is important to better understand the experienced relatedness as it is related to IM, which – as confirmed in RQ3 - in turn is positively correlated with learning achievement scores. This result is in line with the study of Giesbers et al. (2013a).

Results on RQ4 indicated that - as hypothesized - students' IM decreased over time, yet, students' IM was found to be higher during quiz moments than during other moments of the lecture. This finding endorses previous research out of the context of hybrid virtual

learning, stating that quizzes positively impacts students' engagement (Dobbins & Denton, 2017; Kay & LeSage, 2009; Raes et al., 2019). The quizzes were always conducted at the end of the lecture to keep the contextual variance between the settings comparable. However, this can also be seen as a limitation of this study. We found a significant effect of quizzes on students' self-reported IM, but possibly students were more attentive and engaged because they knew that this event predicted the end of the lecture. Second, we should indicate that the temporal assessment of IM has been realized by means of an engagement pop-up, only containing one question, i.e. "How engaged are you now?". As stated in the theoretical framework, engagement is a multifaceted construct involving students' attention, participation, emotional engagement and invested cognitive efforts during a lecture, which is difficult to grasp in one question. It could be argued that this question merely assesses one component of IM, and that this component is less stable than other components. We also have to admit that the temporal self-assessment of engagement was rather intrusive for students. Future research should include less intrusive empirical real time data of the learner experience as for example multimodal learning analytics based on log data, physiological data and computer vision techniques. Furthermore, follow-up research should also focus on the effect of quizzes during synchronous hybrid learning at different time intervals during the lecture to confirm and generalize the finding in this study. Notwithstanding, all students in the focus group stated that they really appreciated the quizzes and half of them even indicated that they would prefer to organize them more frequently during the lecture. Also the results on RQ5 indicate that all students, regardless the learning setting, reported high scores for the perceived usefulness of quizzes and students had highly positive attitudes towards quizzes, in all settings. Future research should also take into account the effect of oral teacher-students interactions as this is also a way to cognitively activate students during lectures.

It should also be mentioned that the teacher's experience was positive thanks to the assistance of the room operator who took over all the operational and technical actions. These actions included the launching of quizzes, giving the microphone to F2F students who wanted to ask or answer a question and keeping control over the logistic processes such as camera direction. As also found by Bower et al. (2015), students did not really like to use the microphone as this felt less spontaneous. In future tests and studies we will explore the opportunities of a throwable microphone (e.g. Catchbox) and a cost-effectiveness analysis will be done regarding ceiling microphones, in order to overcome this barrier. Next to the audio challenge, the system also needs revisions to improve the visibility of the classroom and teacher from the remote perspective. As shown on Fig. 2, the platform now gives remote students the choice to view the slides on the main screen as primary source or to view the teacher, the peers and the slides from the camera they are projected on. Yet, students indicated that on this camera viewpoint, both slides and the teacher were too small. We are currently conducting a research study in which an automated director of the lecture classroom is built, providing video framing depending on lecture activities, e.g. basic directing (close shot, wide shot), showing a lot of faces, just one face, or when to show the projected content at which size. Future studies will also be conducted with more diverse student groups as we realize that although the collaboration with this fixed student group of twelfth graders was beneficial to conduct the within-subject experimental design, the remote experience was rather artificial for them. Future research should also include bigger samples to increase the statistical power and other types of curricular units as this would allow to generalize findings across different curricular units or to study their moderating effect, if any would exist. Additional research should not only include the TAM measures regarding the quizzes organized during the lectures in the hybrid virtual classroom, but should also include the perceived usefulness and perceived ease of use regarding the student and teacher interface of the system in general.

Finally, although literature expresses that the hybrid virtual classroom offers the possibility to reach out to a greater base of potential students and it has the potential to ensure more inclusive education and equality in learning outcomes (Bower et al., 2015; Ørngreen et al., 2015), a good quality of audio and video is a crucial factor of successful remote learning. This means that personal infrastructure at the students' place of choice is a determining factor which puts a high responsibility on the student himself to receive qualitative education. To guarantee successful remote learning a more recent laptop with webcam, a qualitative headset and a stable internet connection is required.

7. Conclusion

Given synchronous hybrid learning is relatively new, there is still a limited number of studies that have investigated its use and effectiveness and the existing literature is mostly exploratory and qualitative in nature. This study aimed to fill this research gap by setting up an empirical, theory-driven study. More specific, this study has set up an experiment to investigate from theself-determination theory how different learning settings can affect students' relatedness, intrinsic motivation and learning achievement in the context of a synchronous learning space. We can conclude that the hybrid virtual classroom is very promising regarding flexibility in course attendance (Lakhal, et al., 2017) as students can choose to come to the campus or to attend the lecture from a location of their own choice. This flexibility also means that students are being exposed to a broader range of views and ideas, because this collaboration and connection between face-to-face and remote students creates richer learning experiences (Bell et al., 2014; Bower et al., 2015). Yet, as confirmed in this study, it is also the most challenging one to teach in and to learn in as a remote participant and the learning environment is still open for improvement regarding the connectivity between face-to-face and remote students. Technology-enhanced quizzes launched through the platform have been found to positively affect students' motivation in all learning settings, but further research that implements different kind of quizzes and during different time intervals is needed to validate this finding in the context of the hybrid virtual classroom. The teacher in this study stated that the educational setting had not really influenced his style of teaching as he could easily start a dialogue with his students in the same way as he is used to do. This is somewhat contradictory with previous literature declaring that this new type of learning environment requires radical shifts in the teachers' pedagogical methods in order to accommodate to the new technology (Cain, 2015; Ramsey et al., 2016). Future research should investigate the effect of different pedagogical scenarios to more deeply investigate how the experience of the remote students

in the hybrid setting can be approved by means of instructional interventions like collaborative (remote) breakout-sessions between F2F and remote students.

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Conflicts of interest

The authors of this manuscript declare to have no conflict of interest.

Ethical approval & informed consent

This research involves human participants, but this research project has been reviewed and approved (tracking number: G-2017 09 908) by the Social and Societal Ethics Committee (https://ppw.kuleuven.be/home/onderzoek/SMEC). Informed consent was obtained from all individual participants included in the study.

References

Abdelmalak, M. M. M., & Parra, J. L. (2016). Expanding learning opportunities for graduate students with HyFlex course design. *International Journal of Online Pedagogy and Course Design, 6*(4), 19–37. https://doi.org/10.4018/IJOPCD.2016100102.

Beatty, B. J. (2007). *Hybrid classes with flexible participation options – If you build it , how will they come ? Paper presented at the 2007 association for educational Communications and technology Annual Convention (October).* (Anaheim, CA).

Beatty, B. (2010). *Hybrid courses with flexible participation.* http://itec.sfsu.edu/hyflex/hyflex_course_design_theory_2.2.pdf Retrieved from.

Bell, J., Sawaya, S., & Cain, W. (2014). Synchromodal classes: Designing for shared learning experiences between face-to-face and online students. *International Journal of Designs for Learning, 5*(1), 68–82.

Bote-Lorenzo, M. L., & Gomez-Sanchez, E. (2017). Predicting the decrease of engagement indicators in a mooc. *Proceedings of the Seventh international learning analytics & knowledge conference* (pp. 143–147). .

Bower, M., Dalgarno, B., Kennedy, G. E., Lee, M. J. W., & Kenney, J. (2015). Design and implementation factors in blended synchronous learning environments: Outcomes from a cross-case analysis. *Computers & Education, 86*, 1–17. https://doi.org/10.1016/j.compedu.2015.03.006.

Bower, M., & Hedberg, J. (2010). A quantitative multimodal discourse analysis of teaching and learning in a web-conferencing environment – the efficacy of student-centred learning designs. *Computers & Education, 54*(2), 462–478. https://doi.org/10.1016/j.compedu.2009.08.030.

Bunce, D. M., Flens, E. A., & Neiles, K. Y. (2010). How long can students pay attention in class? A study of student attention decline using clickers. *Journal of Chemical Education, 87*(12), 1438–1443.

Butz, N. T., & Askim-Lovseth, M. K. (2015). Oral communication skills assessment in a synchronous hybrid MBA programme: Does attending face-to-face matter for US and international students? *Assessment & Evaluation in Higher Education, 40*, 624–639. https://doi.org/10.1080/02602938.2014.940577.

Butz, N. T., & Stupnisky, R. H. (2016). A mixed methods study of graduate students' self-determined motivation in synchronous hybrid learning environments. *The Internet and Higher Education, 28*, 85–95. https://doi.org/10.1016/j.iheduc.2015.10.003.

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.

Butz, N. T., Stupnisky, R. H., Pekrun, R., Jensen, J. L., & Harsell, D. M. (2016). The impact of emotions on student achievement in synchronous hybrid business and public administration programs: A longitudinal test of control-value theory. *Decision Sciences Journal of Innovative Education, 14*(4), 441–474.

Butz, N. T., Stupnisky, R. H., Peterson, E. S., & Majerus, M. M. (2014). Motivation in synchronous hybrid graduate business programs: A self-determination approach to contrasting online and on-campus students. *Journal of Online Learning and Teaching, 10*(2), 211–227.

Cain, W. (2015). Technology navigators: An innovative role in pedagogy, design and instructional support. In P. Redmond, J. Lock, & P. Danaher (Eds.). *Educational innovations and contemporary technologies: Enhancing teaching and learning* (pp. 21–35). UK: Palgrave Macmillan.

Cain, W., Bell, J., & Cheng, C. (2016). Implementing robotic telepresence in a synchronous hybrid course. *Proceedings - IEEE 16th international conference on Advanced learning technologies, ICALT: Vol. 2016*, (pp. 171–175). . https://doi.org/10.1109/ICALT.2016.79.

Chen, K. C., & Jang, S. J. (2010). Motivation in online learning: Testing a model of selfdetermination theory. *Computers in Human Behavior, 26*(4), 741–752. https://doi.org/10.1016/j.chb.2010.01.011.

Cohen, L., Manion, L., & Morrison, K. (2011). *Research methods in education* (7th ed.). London: Routledge.

Creswell, J. W., & Plano Clark, V. L. (2010). *Designing and conducting mixed methods research* (2nd ed.). Thousand Oaks, CA: Sage.

Cunningham, U. (2014). Teaching the disembodied: Othering and activity systems in a blended synchronous learning situation. *International Review of Research in Open and Distance Learning, 15*(6), 33–51.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13*(1), 319–340. https://doi.org/10.2307/249008.

Deci, E. L., & Ryan, R. M. (1985). The general causality orientations scale - self-determination in personality. *Journal of Research in Personality, 19*(2), 109–134.

Dietz-Uhler, B., Fisher, A., & Han, A. (2007). *Designing online courses to promote student retention.* Grant, M. M., & Cheon, J. (2007). The value of using synchronous conferencing for instruction and students. The Journal of Interactive Online Learning, 6(3), 211–226.

Dobbins, C., & Denton, P. (2017). MyWallMate: An investigation into the use of mobile technology in enhancing student engagement. *TechTrends, 61*(6), 541–549. https://doi.org/10.1007/s11528-017-0188-y.

Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School engagement: Potential of the concept, state of the evidence. *Review of Educational Research, 74*(1), 59–109. https://doi.org/10.3102/00346543074001059.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., et al. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences, 111*(23), 8410–8415.

Giesbers, B., Rienties, B., Tempelaar, D., & Gijselaers, W. (2013a). A dynamic analysis of the interplay between asynchronous and synchronous communication in online learning: The impact of motivation. *Journal of Computer Assisted Learning, 30*(1), 30–50. https://doi.org/10.1111/jcal.12020.

Giesbers, B., Rienties, B., Tempelaar, D., & Gijselaers, W. (2013b). Investigating the relations between motivation, tool use, participation, and performance in an e-learning course using web-videoconferencing. *Computers in Human Behavior, 29*(1), 285–292. https://doi.org/10.1016/j.chb.2012.09.005.

Gobert, J. D., Baker, R. S., & Wixon, M. B. (2015). Operationalizing and detecting disengagement within online science microworlds. *Educational Psychologist, 50*(1), 43–57. https://doi.org/10.1017/CBO9781107415324.004.

Grant, M. M., & Cheon, J. (2007). The value of using synchronous conferencing for instruction and students. *The Journal of Interactive Online Learning, 6*(3), 211–226.

Hastie, M., Hung, I. C., Chen, N. S., & Kinshuk (2010). A blended synchronous learning model for educational international collaboration. *Innovations in Education & Teaching International, 47*(1), 9–24. https://doi.org/10.1080/14703290903525812.
Huang, Y., Shu, F., Zhao, C., & Huang, J. (2017). Investigating and analyzing teaching effect of blended synchronous classroom. In J. Liu, S. Nishimura, H. Zhang, & Q. Jin (Eds.). *2017 6TH international conference of educational innovation through technology (EITT)* (pp. 134–135). . https://doi.org/10.1109/EITT.2017.40.
Irvine, V., Code, J., & Richards, L. (2013). Realigning higher education for the 21st-century learner through multi-access learning. *Journal of Online Learning and Teaching, 9*(2), 172–186.
Kay, R. H., & LeSage, A. (2009). A strategic assessment of audience response systems used in higher education. *Australasian Journal of Educational Technology, 25*(2), 235–249. Retrieved from https://doi.org/10.14742/ajet.1152.
Kizilcec, R. F., Pérez-Sanagustín, M., & Maldonado, J. J. (2017). Self-regulated learning strategies predict learner behavior and goal attainment in Massive Open Online Courses. *Computers & Education, 104*, 18–33. https://doi.org/10.1016/j.compedu.2016.10.001.
Koller, D., Ng, A., Do, C., & Chen, Z. (2013). *Retention and intention in massive open online courses: In depth. Educause Review.* Retrieved from http://er.educause.edu/articles/2013/6/retention-and-intention-in-massive-open-onlinecourses-in-depth.
Lakhal, S., Bateman, D., & Bédard, J. (2017a). Blended synchronous delivery modes in graduate programs: A literature review and its implementation in the master teacher program. *Collected Essays on Learning and Teaching, 10*, 47–60. https://doi.org/10.22329/celt.v10i0.4747.
Lakhal, S., De Sherbrooke, U., & Bateman, D. (2017b). Blended synchronous delivery mode in graduate programs: A literature review and its implementation in the master teacher program. *Collected Essays on Learning and Teaching,* 47–60. https://doi.org/10.22329/celt.v10i0.4747.
Lightner, C. A., & Lightner-Laws, C. A. (2016). A blended model: Simultaneously teaching a quantitative course traditionally, online, and remotely. *Interactive Learning Environments, 24*, 224–238. https://doi.org/10.1080/10494820.2013.841262.
Marshall, S. J. (2018). *Shaping the university of the future: Using technology to catalyse change in university learning and teaching.* Retrieved from https://link.springer.com/book/10.1007%2F978-981-10-7620-6.
McGovern, N., & Barnes, K. (2009). Lectures from my living room: A pilot study of hybrid learning from the students' perspective. In F. L Wang, J. Fong, L. Zhang, & V. S. K. Lee (Eds.). *Hybrid learning and education* (pp. 284–298). Berlin, Germany: Springer.
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/10.1177/1477878509104318.
Nortvig, A.-M. (2013). *The presence of technology - teaching in hybrid synchronous classrooms. Proceedings of the European Conference on E-Learning* (pp. 347–353). ECEL.
Olt, P. A. (2018). Virtually there: Distant freshmen blended in classes through synchronous online education. *Innovative Higher Education, 43*(5), 381–395. https://doi.org/10.1007/s10755-018-9437-z.
Ørngreen, R., Levinsen, K., Jelsbak, V., Moller, K. L., & Bendsen, T. (2015). Simultaneous class-based and live video streamed teaching: Experiences and derived principles from the bachelor programme in biomedical laboratory analysis. In A. Jefferies, & M. Cubric (Eds.). *Proceedings of the 14th european conference on E-learning (ECEL 2015)* (pp. 451–459). UK: Academic Conferences and Publishing International Limited.
Raes, A., Detienne, L., Windey, I., & Depaepe, F. (2019). *A systematic literature review on synchronous hybrid learning: gaps identified.* Accepted for publication in Learning Environments Research.
Raes, A., & Depaepe, F. (2019). A longitudinal study to understand students' acceptance of technological reform. When experiences exceed expectations. *Education and Information Technologies*. https://doi.org/10.1007/s10639-019-09975-3.
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 & Development, 63*(3), 405–430. https://doi.org/10.1007/s11423-015-9381-x.
Raes, A., Windey, I., Beernaert, T., Bonte, P., Vanherweghe, G., Detienne, L., et al. (2019). *Towards technology-enhanced, interactive learning spaces in higher education. Accepted for publication in the Educational Technology Section of the Routledge Encyclopedia of Education*.
Ramsey, D., Evans, J., & Levy, M. (2016). Preserving the seminar experience. *Journal of Political Science Education, 12*(3), 256–267. https://doi.org/10.1080/15512169.2015.1077713.
Rasmussen, R. C. (2003). *The quantity and quality of human interaction in a synchronous blended learning environment*Doctoral dissertation. Brigham Young University Available from: ProQuest Dissertations & theses. (UMI No. 305345928). .
Roca, J. C., & Gagné, M. (2008). Understanding e-learning continuance intention in the workplace: A self-determination theory perspective. *Computers in Human Behavior, 24*(4), 1585–1604. https://doi.org/10.1016/j.chb.2007.06.001.
Scherer, K. R. (2005). What are emotions? And how can they be measured? *Social Science Information, 44*, 693–727.
Selfdeterminationtheory.org. Retrieved from http://selfdeterminationtheory.org/intrinsic-motivation-inventory/.
Short, J., Williams, E., & Christie, B. (1976). *The social Psychology of Telecommunications.* London: John Wiley & Sons, Ltd978-0471015819.
Stupnisky, R. B., & Butz, N. T. (2016). A mixed methods study of graduate students' self-determined motivation in synchronous hybrid learning environments. *The Internet and Higher Education, 28*, 85–95. https://doi.org/10.1016/J.IHEDUC.2015.10.003.
Szeto, E. (2014). A Comparison of online/face-to-face students' and instructor's experiences: Examining blended synchronous learning effects. *Procedia - Social and Behavioral Sciences, 116*, 4250–4254. https://doi.org/10.1016/j.sbspro.2014.01.926.
Szeto, E. (2015). Community of inquiry as an instructional approach: What effects of teaching, social and cognitive presences are there in blended synchronous learning and teaching? *Computers & Education, 81*, 191–201. https://doi.org/10.1016/j.compedu.2014.10.015.
Tajfel, H. (1979). Individuals and groups in social psychology. *British Journal of Social & Clinical Psychology, 18*, 183–190. https://doi.org/10.1111/j.2044-8260.1979.tb00324.x.
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.
Wang, Q., Quek, C. L., & Hu, X. (2017). Designing and improving a blended synchronous learning environment: An educational design research. *International Review of Research in Open and Distance Learning, 18*(3), 99–118.
Weitze, C. L. (2015). Pedagogical innovation in teacher teams: An organisational learning design model for continuous competence development. In A. Jefferies, & M. Cubric (Eds.). *Proceedings of 14th European Conference on e-Learning ECEL-2015 (s. 629-638)*. Reading, UK: Academic Conferences and Publishing International.
Weitze, C. L., Ørngreen, R., & Levinsen, K. (2013). The global classroom video conferencing model and first evaluations. In I. M. Ciussi, & M. Augier (Eds.). *Proceedings of the 12th european conference on E-learning: SKEMA Business school, Sophia Antipolis France, 30-31 October 2013 (Bind 2, s. 503-510). Reading, UK: Academic Conferences and publishing international*.
White, C. P., Ramirez, R., Smith, J. G., & Plonowski, L. (2010). Simultaneous delivery of a face-to-face course to on-campus and remote off-campus students. *TechTrends, 54*(4), 34–40. https://doi.org/10.1007/s11528-010-0418-z.
Wiles, G. L., & Ball, T. R. (2013, June 23-26). *The converged classroom. Paper presented at 2013 ASEE Annual Conference: Improving course effectiveness.* Atlanta, Georgia https://peer.asee.org/22561.
Wilson, K., & Korn, J. H. (2007). Attention during lectures: Beyond ten minutes. *Teaching of Psychology, 34*(2), 85–89. https://doi.org/10.1080/00986280701291291.
Witmer, B. G., Jerome, C. J., & Singer, M. J. (2005). The factor structure of the presence questionnaire. (2005). *Presence: Teleoperators and Virtual Environments, 14*(3), 298–312. https://doi.org/10.1162/105474605323384654.
Zydney, J. M., McKimm, P., Lindberg, R., & Schmidt, M. (2019). Here or there instruction: Lessons learned in implementing innovative approaches to blended synchronous learning. *TechTrends, 63*(2), 123–132. https://doi.org/10.1007/s11528-018-0344-z.

Annelies Raes holds a PhD in Educational Technology by Ghent University and now works as Postdoctoral Researcher in Instructional Psychology and – Technology at the University of Leuven (KU Leuven), campus Kulak in Kortrijk, Belgium. She is also co-Principal Investigator within imec's Smart Education Program (https://www.imec-int.com/en/articles/smart-education). Her main fields of interests are new innovative education models as active learning and problem-based collaborative learning and how this can be supported by emergent technologies.