Adaptive Learning Technologies In Blended Learning Design: How Do Students and Teachers Use This Technology in Practice?

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Blended learning is adopted as the teaching method in an increasing number of higher education institutes worldwide. Adaptive learning technology (ALT) can be incorporated in such learning designs, especially to support students' a-synchronous, individual learning activities. In this empirical, mixed-method study, we investigated in what way teachers and students use the provided functionalities of a specific ALT to realise a blended course design. We interviewed four teachers delivering the same course using the ALT and we quantitatively analysed student trace data from the ALT log system. Our results show that teachers do recognize the added value of employing an ALT, but they do not realise its full potential by lack of usage of the dashboard, knowledge sharing among teachers and too little attention for (meta)cognitive and social support of students. The trace data analysis shows that students display cramming behaviour (no repetition and/or spaced practice), they are selective in which learning objectives they study and a majority chooses a suboptimal learning path. Based on our results, we conclude that, in the case we studied, the full potential that the ALT offers is not realised to the benefit of students, since both teachers and students show suboptimal behavior. We give recommendations for practice and future research based on our conclusions.

Keywords: blended learning, active learning, adaptive learning technologies, case study, Bled eConference

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1 Introduction

Blended education is high on the agendas of educational institutions, especially after the Covid pandemic (Bruggeman et al., 2022; Dziuban et al., 2018). By combining the strengths of different learning environments, students can have a richer learning experience. In order to provide students with a rich learning environment in which they actively learn independent of time and/or place, a-synchronous learning activities are often part of students' learning arrangements.

The deployment of adaptive learning technologies for these a-synchronous learning activities has grown rapidly and these technologies are increasingly used in educational settings. Real-time interaction is not needed in those learning activities, as students interact when they want and at their own pace with course content through, among others, screencasts, exercises, and discussion boards. As a consequence, in theory there is more time at school for students to interact about course contents with peers and teachers synchronously. In practice, we often see that students and teachers do not take enough advantage of the used adaptive technologies. Students do not always prepare enough to effectively use the time in the classroom for further understanding of all learning content. And teachers do not always (know how to) use all provided information in the dashboards about students' progress to actively (change the) focus of the live interactions to the topics that students consider difficult.

A main goal of adaptive technologies is supporting active learning. Therefore, the current study focuses on teachers' possibilities to reach this goal by using adaptive learning technologies in a course design and aims to answer the question: *"How do teachers and students use adaptive technologies in practice and what can they do to contribute to active learning by students?"*

2 Theoretical framework

2.1 Blended and Active Learning

Hrastinski analysed the many definitions of blended learning and came to the conclusion that blended learning has become "an umbrella term" (Hrastinski, 2019). Therefore, he recommends explicitly stating what is understood by blended learning

in the context of specific research. In addition, research at the higher education institute in the Netherlands where this study took place has concluded that many of the definitions of blended learning (Kat-De Jong, 2021): (1) place too much emphasis on the distinction between physical and online education; and/or (2) place too much emphasis on the ICT aspect; and/or (3) insufficiently reason from the student's perspective. Subsequently, within this institute blended learning has been defined as: "Providing a rich learning experience as a result of a deliberate, integrated, and harmonious combination of synchronous and a-synchronous learning activities in which students participate remotely, on campus, and in the workplace.".

Bernard et al. (2014) conclude from various comparative studies that a blended learning arrangement leads to better results for students (e.g., regarding motivation, engagement, and grades) than a fully offline or a fully online setup. In addition, Van der Stappen (2022) concludes that the added value of blended learning can be achieved precisely then when effectively combining the strengths of different learning environments, i.e., on campus, in the online learning environment, and in the workplace.

Various international meta-studies have studied the added value of blended learning, which can be summarized as follows (Last & Prinsen, 2021): (1) Blended learning can increase students' *engagement and learning efficiency*; (2) Blended learning offers *flexibility* in place and (partly) time of learning, e.g. for (the growing group of) international and working students; (3) Blended learning can potentially *maximize the benefits of several places while reducing their weaknesses* by combining online and face-to-face learning activities; and (4) Blended learning can increase students' *confidence* in their own abilities (self-efficacy) and *intrinsic motivation*.

Active learning is the central concept within the active (blended) learning ecosystem (Hedgepath, 2014; Last & Jongen, 2023).. If well-designed, blended learning motivates and activates students. This implies that students need to take ownership of their own learning process and, thus, need to engage in self-regulated learning (Jansen, 2021). However, self-regulated learning skills do not develop naturally, and research shows that the vast majority of students struggle to actually self-regulate their learning properly (Bol & Garner, 2011). In order for students to actually achieve a state of active learning, all three aspects of the aforementioned ecosystem (i.e.

pedagogy, physical and virtual space, and technology) are to be considered integrally by teachers when designing and evaluating blended learning arrangements that support active learning.

2.2 Community of Inquiry

Although not developed specifically for blended learning, the Community of Inquiry framework is one of the most influential blended learning models (Hrastinski, 2019). It has been argued that it is useful for understanding and designing blended learning due to the generic nature of the framework, and the resonance with both face-to-face and online learning (Garrison & Vaughan, 2008). The Community of Inquiry framework represents a process of creating a deep and meaningful (collaborative-constructivist) learning experience through the development of three interdependent elements (Garrison et al., 2001):

- *Social presence*: the ability of learners to project their personal characteristics into the Community of Inquiry, thereby presenting themselves as "real people". Intervention categories (Arbaugh et al., 2008): affective expression, open communication, and group cohesion;
- *Cognitive presence*: the extent to which the participants in any particular configuration of a Community of Inquiry are able to construct meaning through sustained communication. Intervention categories (Arbaugh et al., 2008): activating activities, exploration, integration, and completion;
- *Teaching presence*: the design, facilitation, and direction of cognitive and social processes for the purpose of realizing personally meaningful and educational worthwhile learning outcomes. Intervention categories (Arbaugh et al., 2008): design & organization, facilitating discourse, and direct instruction.

The idea behind this framework is that teachers create a blended learning environment encompassing a strong (interaction between) social, cognitive and teaching presence.

2.3 Adaptive Learning Technologies

With Covid and home-schooling as major accelerators, the deployment of adaptive learning technologies has increased significantly. A learning environment is adaptive *"…to the degree that (a) its design is based on data about common learner challenges in the target subject matter, (b) its pedagogical decision-making changes based on psychological measures of individual learners, and (c) it interactively responds to learner actions*." (Aleven et al., 2016). Although adaptive learning technologies have been considered an important trend in education, they still have not reached their full potential as of yet, possibly since there has not been enough attention for the role of these technologies in the design of rich learning experiences (Rivera Muñoz et al., 2022; Weber et al., 2019).

In terms of blended learning, adaptive learning technologies are mainly used for a-synchronous learning activities. A-synchronous learning does not require real-time interaction. Students interact with the course content at their own pace, when and where they want, through e.g., learning modules, discussion boards, or pre-recorded videos.

Assuming that students engage with the materials in line with the teacher's blended course design, the idea is that students arrive well-prepared at the synchronous, on campus learning activity (e.g., a classroom lecture or workshop). That would result in more time to interact about course contents with peers and teachers synchronously in order to deepen and/or broaden the students' knowledge. The design of such a blended learning arrangement is frequently illustrated as a "blended wave". A fictitious example is presented in Figure 1 (SURF, 2022).

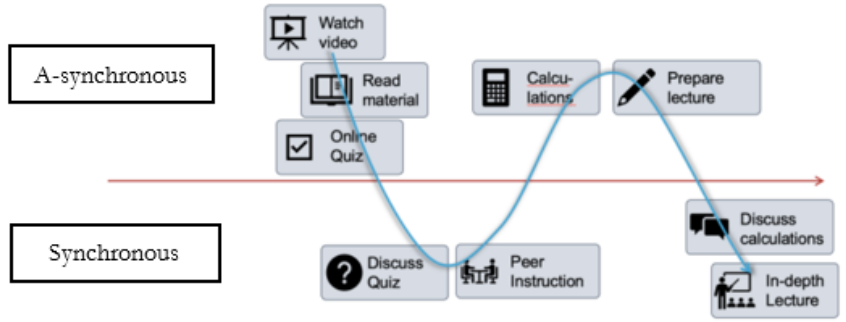

Figure 1: Example of a blended learning arrangement designed as a "blended wave"

3 Methodology

In this study, we want to understand better if and how a course – designed as a "blended wave" and supported by adaptive learning technology (ALT) – works in practice. Ultimately, we want to identify opportunities for (blended) educational improvements. Therefore, we answer the following research question: *"How do teachers and students use adaptive technologies in practice and what can they do to contribute to active learning by students?* To answer this question, we performed a mixed-method single case study (Yin, 2018). Below, we describe the real-world educational context in which the study took place, as well as the participants in the study, and the instruments and the methods that were used.

3.1 Context

The study was performed at a large university of applied sciences in the Netherlands with a focus on the course Introduction to Business Economics in the fall of 2021. This course is offered in both the Human Resources Management ("HRM") and Business Administration ("BA") Bachelor programmes.,during the first quarter of the propaedeutic phase, hence the students in question are on average 17-18 years of age.

The blended learning activities took place during seven consecutive teaching weeks. During these seven weeks, students engaged in the adaptive tool (a-synchronous) and had one (synchronous) lecture per week. Neither engaging in the adaptive tool nor participating in the lectures was compulsory. The eighth week was used for preparing (a-synchronously) for the written exam. This exam was taken in the ninth week.

The *ALT (software)* in this study is provided by a Dutch company: ABC (fictious name). ABC's software supports setting up the aforementioned "blended wave" (see Figure 1). For a student, ABC's software includes among others a question module. For a teacher, ABC's software includes among others a teacher dashboard.

The course in scope of our research is constructed along twelve learning objectives (subjects/themes). These learning objectives have a suggested order (learning objective sequence 1-12 as captured in the trace data; see section 3.2). However, the

software does not prescribe a student to start with a specific learning objective in the software, nor which order to follow. Hence, a student can start with learning objective 11 and subsequently go to learning objective #5, from there to #7, etc.

By answering questions in the question module, a student can increase the so-called "ABC score". This is a grade number (1-10) that reflects the students' progress per learning objective and across all learning objectives. The ABC score can be increased or decreased, according to an algorithm, by answering questions in the module correctly or incorrectly. In maximally four steps, the students receive feedback on their incorrect answer attempts to instantly help the student proceed; this is referred to as "scaffolding" (Rivera Muñoz et al., 2022). The ABC score is also disclosed to a teacher via the aforementioned teacher dashboard. Appendix A contains a further explanation about the ALT in this case study.

3.2 Research Design

The research is designed as a mixed-method single case study, where the unit of analysis is the execution of a blended course design using ALT for a-synchronous activities. We applied triangulation (Cohen et al., 2018) in the data collection in several ways: both qualitative and quantitative methods were used, and data was collected from both teachers and students involved in the same course.

Semi-structured *interviews* were conducted with four teachers involved in the course (Table 1). Each interview was audio-recorded, fully transcribed and coded using open coding (Flick, 2018). The interview questions – reviewed by a second researcher – were targeted at teacher knowledge of adaptive learning and the associated technology, their views on the three aspects of the Community of Inquiry Framework, and the usage of the specific ALT applied in the course they were teaching. All teachers were informed of the purposes of our study, the data management and all gave recorded oral consent.

Moreover, a *quantitative analyses* on the log trace data extracted from the ALT which logs most of the students' online actions was performed. The original data file (Excel format) was retrieved anonymised from ABC. The trace data reflects the logging of all student activities in the question module in the period September 2021 to January 2022 for the course. Please refer to Appendix B for a further explanation about the

original trace data as well as the cleaning and augmentation actions performed by the researchers. The data analysis was limited to activities in week 1 up to and including week 9 (written exam). The activities of nine students were discarded from the trace data set, either because these students were only enrolled to re-take the exam after failing the year before, or because they were not assigned to a class group which was supervised by a teacher. The final data set thus contains the data of 273 - 9 = 264 (mostly first year) students. No personal information (e.g., gender or age) was collected, since it was deemed unnecessary to answer the research question in this study. The students gave consent for the use of their log data in the system for research and improvement purposes when enrolling in the ALT system.

Table 1: Participant (interviewee) information

Interviewee	Teacher Experience	Used ALT In Scope Before?
A	**5 years**	**Yes, 4 years**
B	**8 years**	**Yes, 4 years**
C	**9 years**	**Yes, 3 years**
D	**15 years**	**No**

4 Results

4.1 Interviews with teachers

4.1.1 Ambiguous definitions

The interviewees mentioned various definitions of adaptive learning/adaptivity. The answers had in common that teachers were thinking about more student-tailored education. A few examples can be found in Table 2.

Table 2: Quotes on the definition of adaptive learning

Interviewee	Quote
A	*"Thinking along, giving tips, supporting/promoting the learning process, customisation, individual and immediate insight into 'right or wrong' but especially into why this was the case, adapting to level (of questions), different ways of learning (reading, videos), own pace, own moment."*
B	*"…tailoring your programme to your students. Customisation. And that means you underrstand how a particulat student learns and you take this as a starting point."*
C	*"...that students can partly learn at their own pace. So working on something by themselves and using that to find out for which topic(s) there is a need for help...so that you can match what each individual student needs."*
B+D	*"...time-independent and location-independent, self-paced learning."*

4.1.2 Motivations for deployment of the ALT

The interviewees mentioned several reasons for deploying an ALT such as the one deployed in this study. These vary from provider's sales push to the belief that the language and word usage in the ALT are much more in line with today's students. Most predominant is the belief that an ALT supports the concept "students in the lead": moving from consuming to demand-driven learning. Furthermore, direct, concrete feedback provided by the software means students do not have to wait (long) for a response from a teacher and can move on more quickly. Direct, concrete feedback can avoid misconceptions: "*Suppose the answer is EUR 100,000, a student may start working towards this answer, but not in the correct way. He/she therefore learns an incorrect method at that point. The ALT prevents this.*" Another important motivation is referred to as "no ballast": "*...the ALT compresses the material to its essence; in the previously used textbook, about 2/3rds of the content is not covered in the course.*"

4.1.3 Teachers recognize added value, but also make critical comments

The perceived benefits of using an ALT by the interviewees play an important role in supporting the deployment of an ALT. However, the interviewees also made some critical comments. Most importantly, the ALT is constructed along micro learning objectives. This leads to students *"…continue to 'think micro': students struggle to make connections between the individual learning objectives and/or to oversee the whole course with a helicopter view. Furthermore, students quickly get used to the way questions are formulated in the*

ALT's question module". In the ALT, topics as well as questions are structured per (micro) learning objective. However, during their written exam, students need to combine all information by solving an integrated case. As many students face difficulties with these kinds of cases, teachers need to explicitly address those while offering the blended learning arrangement. Otherwise the required constructive alignment is not in place (Biggs & Tang, 2011). To overcome this, as stated in the interviews, teachers started experimenting with so-called "integration case studies", which have been aligned with the ALT's supplier. These case studies are discussed during the synchronous, on campus, lessons. The preliminary results, based on feedback about the deployment of these "integration case studies" from both teachers and students, are promising.

4.1.4 Teaching presence dominant

The interviewees heavily focussed on interventions related to teaching presence. This is mainly due to the tangibility of and familiarity with the intervention categories related to teaching presence, i.e.: design & organisation, teaching facilitation and direct instruction (Arbaugh et al, 2008). For each of these aspects, without having to think for long, teachers named concrete examples of teaching presence related interventions in the context of this course.

This applies to a much lesser extent to social and cognitive presence. When asked, these two concepts are not directly recognised and the teachers make only (very) limited use of conscious, explicit interventions to promote social and cognitive presence. The deployment of the aforementioned integration case studies is the main example provided by the interviewees concerning cognitive presence. Three of the interviewees explicitly indicated that no specific a-synchronous social presence interventions were organised during this series of lessons, neither to interact with peers nor with teachers. However, research shows that students "…value , above all, regular synchronous and a-synchronous interactions with peers, tutors…" (Armellini et al., 2021).

4.1.5 Teacher dashboard could be used more effectively

The interviewees indicated that the capabilities of the teacher dashboard were only partially used. Teachers reported using the dashboard mainly in the first two weeks. In doing so, some teachers chose to open the dashboard in class ("confrontation"), others to address students 1-on-1. After a few weeks, the use of the teacher dashboard decreased. Reason are that a certain "*dashboard fatigue*" had developed and, in addition, the effect on the students by (publicly) displaying the dashboard seemed to be had worn off by then. Within the teacher dashboard, the ABC score (grade; 1-10) was mainly looked at, much less at the number of activity and attempts. Therefore, the teachers missed relevant information such as: (1) The questions/learning objectives for which the students needed the most response attempts in order to reach a sufficient result; (2) Students who were 'skipping' learning objectives; and (3) Students who were going through the various learning objectives in an undesirable sequence.

4.1.6 Teachers did not sufficiently share or discuss

As a group of teachers, it is important to share and discuss beliefs (or obstacles) considering the aforementioned elements (Gremmen, 2022). Ideally, this is done on a regular basis before (designing), during (adjusting/fine-tuning), and after (evaluating) the series of lessons. The interviewees indicated that mutual discussions heavily focused on course content instead of on beliefs (or obstacles) about active and blended learning in general, adaptive learning (techniques), cognitive and social presence interventions, dashboard deployment, etc.

4.2 Student trace data analysis

The trace data from the ALT was analysed from various perspectives such as number of activities (number of questions answered and number of response attempts per question), learning objectives, and ABC score. The results show a significant drop in students' activities in the ALT after week 2, lasting until week 7 (see Figure 2). The written exam was in week 9; the higher activity in week 8 might indicate a-synchronous last-minute exam preparation. This *cramming behaviour* is not in line with recommendations from research on effective (blended) learning strategies, such as repetition and spaced practice (Yeung et al., 2021).

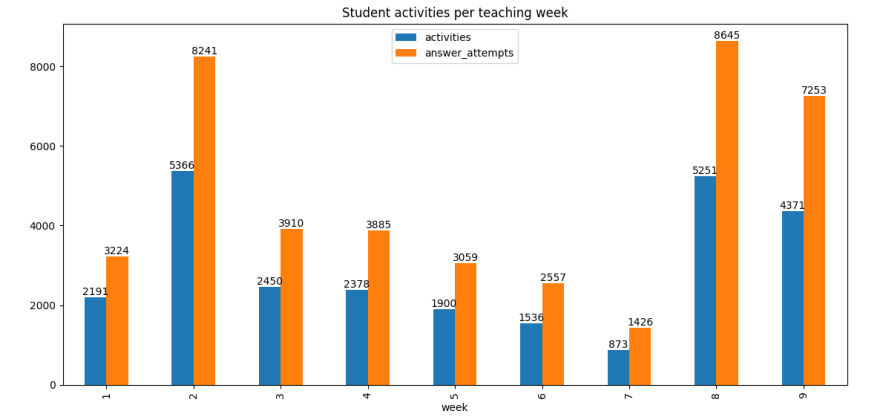

Figure 2: Number of activities and attempts performed by students per week

The ALT does not prescribe a student to start with a specific learning objective in the software, nor which order of learning objectives to follow, whereas the learning objectives do in fact build on the content of the previous one(s). Therefore, it was analysed which learning objective students chose to study in the system, and in which order. Here, *visiting* a learning objective (i.e., attempting at least one question related to this objective) is distinghuished from *completing* it (i.e., gaining a sufficient ABC score of at least 6.0).

Just 136 out of 264 (51%) of the students visited all learning objectives and only 156 (60%) of the students started the final learning objective #12 (See Figure 3) Therefore, it was analysed which learning paths (=learning objective sequence) students chose; see Figure 3 and Figure 4.

In Figure 4, all chosen learning paths are shown as line plots, with line thickness representing the number of students chosing that path. Most students stayed close to the default path, but some outliers exist, choosing for example the learning path (#5, #7, #1, #2, #9, #10, #11). 111 students chose the *default path*, i.e., #1 through #12. Nonetheless, there is a great variety in learning paths, e.g., 13 students never visited learning objective #1, one student started with #6, and one student visited #11 as his/her second objective.

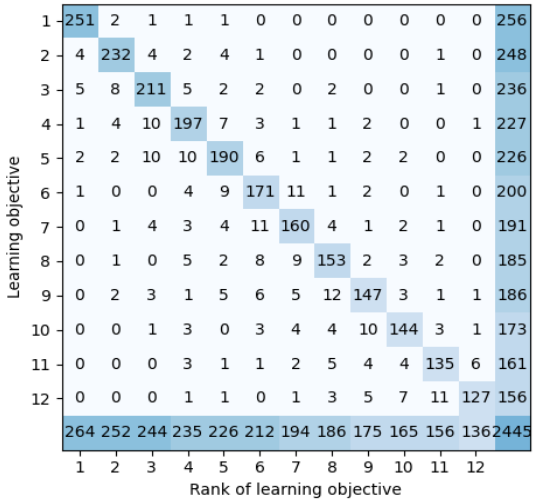

Figure 3: Students visiting a given learning objective at a given rank

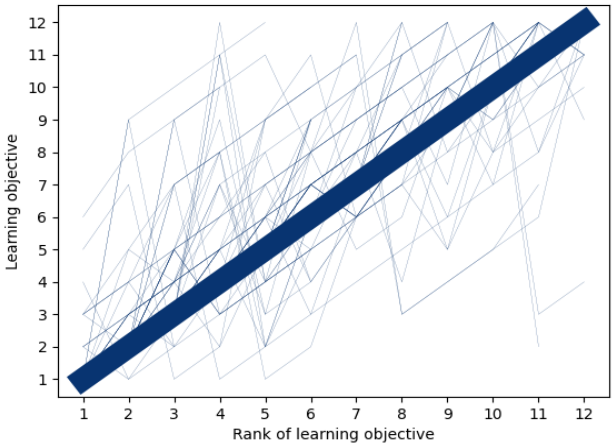

Figure 4: Learning paths chosen by students

Finally, the maximum ABC scores that students achieved on each of the learning objectives to compare scores between students that chose the default path and those that chose different paths was analysed. The complete results are shown in Table 3. An unpaired, two-sided T-test was performed. The difference between the average ABC score for default paths ($M_{default}$=7.70, $SD_{default}$=0.80) and the average ABC score for different paths ($M_{different}$=6.28, $SD_{different}$=1.80) is statistically significant, $t_{222.90485}$=8.65, p=1.00e-15, 95% CI [1.0964, 1.7431]. The results in Table 3 and the T-test point in the direction that students that chose the default learning path outperformed those that didn't, in terms of ABC score.

Table 3: Absolute and relative numbers of students scoring (in)sufficient on learning objectives

	default path (N=111)			different path (N=153)			total visited	% visited (N=264)
learning goal	insufficient	sufficient	% sufficient	insufficient	sufficient	% sufficient		
1	1	110	99.1%	17	128	83.7%	256	97.0%
2	3	108	97.3%	19	118	77.1%	248	93.9%
3	6	105	94.6%	17	108	70.6%	236	89.4%
4	1	110	99.1%	15	101	66.0%	227	86.0%
5	21	90	81.1%	60	55	35.9%	226	85.6%
6	1	110	99.1%	14	75	49.0%	200	75.8%
7	2	109	98.2%	22	58	37.9%	191	72.3%
8	1	110	99.1%	4	70	45.8%	185	70.1%
9	9	102	91.9%	25	50	32.7%	186	70.5%
10	2	109	98.2%	16	46	30.1%	173	65.5%
11	6	105	94.6%	14	36	23.5%	161	61.0%
12	14	97	87.4%	14	31	20.3%	156	59.1%

5 Conclusions and Discussion

In this study, we aimed to answer the question: '*How do teachers use adaptive technologies and what can they do to contribute to active learning by students?*' by interviewing teachers and analysing student trace data. Results show that both groups do not utilize the ALT in question as intended, i.e., to realize active learning through a blended wave in the course design. This is in line with other studies on ALTs, which were not specifically focused on blended learning designs (Harati et al., 2021). Our study adds to the knowledge base on ALT, since studies tend to focus more on technology than on learning (Rivera Muñoz et al., 2022).

Teachers show prominent teaching presence where cognitive and social presence are underrepresented. For an optimal blended learning experience, teachers should employ a balanced mix of these three presences, with cognitive presence being a strong indicator of students' satisfaction (Giannousi & Kioumourtzoglou, 2016). Students display cramming behaviour (no repetition and/or spaced practice), they are selective in which learning objectives they study and a majority chooses a suboptimal learning path.

Based on our research, we formulate some recommendations for educational practice. First, we advise teachers to actively integrate (insights from) the ALT in their synchronous activities, utilising the dashboard, and to use interventions directed at social and cognitive presence such as instruction on effective learning strategies or open communication aimed at community building (Biwer et al., 2020). These recommendations are in line with the recommendations from a recent study Müller et al. (2023). In addition, teachers could share their beliefs and strategies related to active, blended learning and ALTs when implementing a blended course with ALT to learn from each other. The ALT system could be extended to help students overcome drops in engagement by sending reminder notifications or employ (gamified) nudges. In the previous months, we conducted an exploratory study with students to assess the technical feasibility of such nudges based on machine learning analyses, and the preliminary results are promising.

Our study has some limitations. It took place in a specific context, where characteristics of teachers, students and technology may have influenced the results. The student participants group was quite large (264), but a mere four teachers were interviewed. Moreover, quantitative data was not available on teacher behaviour, and we did not include qualitative student data .

To conclude, we identify some interesting directions for future research. First, we would like to perform the same analyses in other educational contexts, in terms of study domain, teacher and students' characteristics, and ALT used. Second, a more qualitative study directed at students' perspective and behaviour could add to the insights presented in this paper. Finally, since our results show that the behaviour of both teachers and students was suboptimal, we think studies on interventions to help both groups to engage in more effective teaching and study behaviour would be very relevant to increase student success.

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References

Aleven, V., Mclaughlin, E., Glenn, A., & Koedinger, K. (2016). Instruction Based on Adaptive Learning Technologies.

Arbaugh, J. B., Cleveland-Innes, M., Diaz, S. R., Garrison, D. R., Ice, P., Richardson, J. C., & Swan, K. P. (2008). Developing a community of inquiry instrument: Testing a measure of the Community of Inquiry framework using a multi-institutional sample. The Internet and Higher Education, 11(3–4), 133–136. https://doi.org/10.1016/j.iheduc.2008.06.003

Armellini, A., Teixeira Antunes, V., & Howe, R. (2021). Student Perspectives on Learning Experiences in a Higher Education Active Blended Learning Context. TechTrends, 65(4), 433–443. https://doi.org/10.1007/s11528-021-00593-w

Bernard, R. M., Borokhovski, E., Schmid, R. F., Tamim, R. M., & Abrami, P. C. (2014). A meta-analysis of blended learning and technology use in higher education: From the general to the applied. Journal of Computing in Higher Education, 26(1), 87–122. https://doi.org/10.1007/s12528-013-9077-3

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

Biwer, F., Egbrink, M. G. A. oude, Aalten, P., & de Bruin, A. B. H. (2020). Fostering effective learning strategies in higher education—A mixed-methods study. Journal of Applied Research in Memory and Cognition, 9(2), 186–203. https://doi.org/10.1016/j.jarmac.2020.03.004

Bloom, B. S., Engelhart, M. D., Furst, E. J., Hill, W. H., & Krathwohl, D. R. (1956). Taxonomy of educational objectives: The classification of educational goals: handbook I: cognitive domain. New York, US: D. Mckay.

Bol, L., & Garner, J. K. (2011). Challenges in supporting self-regulation in distance education environments. Journal of Computing in Higher Education, 23(2–3), 104–123.

Bruggeman, B., Hidding, K., Struyven, K., Pynoo, B., Garone, A., & Tondeur, J. (2022). Negotiating teacher educators' beliefs about blended learning: Using stimulated recall to explore design choices. Australasian Journal of Educational Technology, 100–114. https://doi.org/10.14742/ajet.7175

Cohen, L., Manion, L., & Morrison, K. (2018). Research methods in education (Eighth edition). Routledge.

Dziuban, C., Graham, C. R., Moskal, P. D., Norberg, A., & Sicilia, N. (2018). Blended learning: The new normal and emerging technologies. International Journal of Educational Technology in Higher Education, 15(1), 3. https://doi.org/10.1186/s41239-017-0087-5

Flick, U. (2018). An introduction to qualitative research (6th edition). SAGE Publications.

Garrison, D. R., Anderson, T., & Archer, W. (2001). Critical thinking, cognitive presence, and computer conferencing in distance education. American Journal of Distance Education, 15(1), 7–23. https://doi.org/10.1080/08923640109527071

Garrison, D. R., & Vaughan, N. D. (2008). Blended learning in higher education: Framework, principles, and guidelines (1st ed). Jossey-Bass.

Giannousi, M., & Kioumourtzoglou, E. (2016). Cognitive, Social, and Teaching Presence as Predictors of Students' Satisfaction in Distance Learning. Mediterranean Journal of Social Sciences. https://doi.org/10.5901/mjss.2016.v7n2s1p439

Gremmen, M. (2022). What's on teachers minds? Teachers' helping and hindering beliefs about blended education. European Association for Practitioner Research on Instruction and Learning, Nijmegen.

Harati, H., Sujo-Montes, L., Tu, C.-H., Armfield, S., & Yen, C.-J. (2021). Assessment and Learning in Knowledge Spaces (ALEKS) Adaptive System Impact on Students' Perception and Self-Regulated Learning Skills. Education Sciences, 11(10), 603. https://doi.org/10.3390/educsci11100603

Hedgepath, P. (2014). Active Learning. https://www.slideshare.net/hedgepath/lets-flip-it-2014

Hrastinski, S. (2019). What Do We Mean by Blended Learning? TechTrends, 63(5), 564–569.

Jansen, R. (2021, July 20). Zelfregulatie in blended onderwijs | Onderwijskennis. https://www.onderwijskennis.nl/kennisbank/zelfregulatie-blended-onderwijs

Kat-De Jong, M. (2021). Reflectie op blended onderwijs. Verkenning, speelveld en implementatie van blended onderwijs binnen Avans Hogeschool. Breda: Avans Hogeschool.

Last, B., & Jongen, S. (2023). Blended learning design: From theory to practice. Boom.

Last, B., & Prinsen, F. (2021). Blended learning en onderwijsontwerp. https://www.onderwijskennis.nl/kennisbank/blended-learning-en-onderwijsontwerp

Müller, C., Mildenberger, T., & Steingruber, D. (2023). Learning effectiveness of a flexible learning study programme in a blended learning design: Why are some courses more effective than others? International Journal of Educational Technology in Higher Education, 20(1), 10. https://doi.org/10.1186/s41239-022-00379-x

Rivera Muñoz, J., Berríos, H., & Arias-Gonzales, J. (2022). Systematic Review of Adaptive Learning Technology for Learning in Higher Education. Eurasian Journal of Educational Research (EJER), 98, 221–233. https://doi.org/10.14689/ejer.2022.98.014

SURF. (2022). De blended learning wave. https://communities.surf.nl/blended-learning/artikel/de-blended-learning-wave

Van der Stappen, E. (2022). Keuzes maken in blended en flexibel onderwijs: Hoedan#. https://www.avans.nl/onderzoek/expertisecentra/stand-alone-lectoraten/lectoraten/digitale-didactiek/lectorale-rede

Weber, N., Alexander, B., Ashford-Rowe, K., Barajas-Murphy, N., Dobbin, G., Knott, J., McCormack, M., Pomerantz, J., & Seilhamer, R. (2019). Educause Horizon report: 2019 Higher Education edition. EDUCAUSE.

Yeung, K. L., Carpenter, S. K., & Corral, D. (2021). A Comprehensive Review of Educational Technology on Objective Learning Outcomes in Academic Contexts. Educational Psychology Review, 33(4), 1583–1630. https://doi.org/10.1007/s10648-020-09592-4

Yin, R. K. (2018). Case study research and applications: Design and methods (Sixth edition). SAGE.

Appendix A - Further Explanation ALT

The adaptive software is provided by a Dutch company: ABC (fictious name). ABC's software supports setting up the "blended wave" (see Figure A). ABC has developed several courses (modules) that correspond to topics within a curriculum. Each course contains several learning objectives (subjects/themes) that can be completed independently, but which have a logical structure. For example, the course in scope of our research – Introduction to Business Economics – consists of twelve learning objectives. These learning objectives have a suggested order (learning objective sequence 1-12 as captured in the trace data), however the software does not restrict a student to start with a specific learning objective in the tool. Hence, a student could start with learning objective #4 or even with the last one (#12).

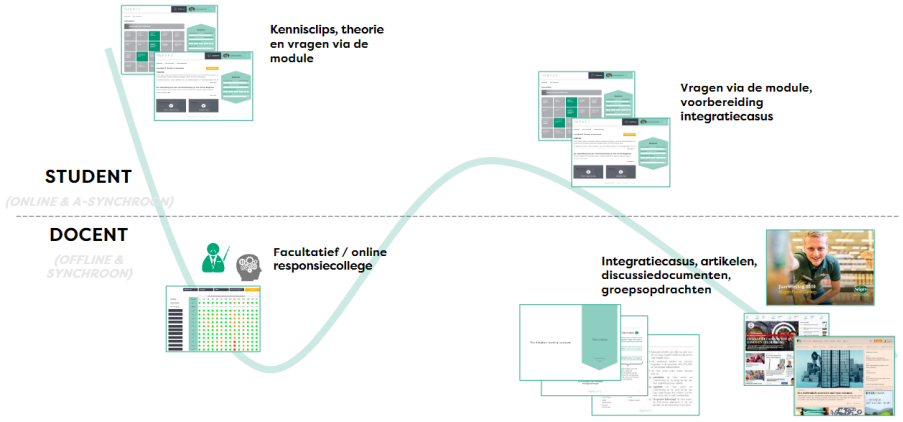

Figure A: The "blended wave" supported by the ALT

This "blended wave" ensures – at least that is the philosophy behind this software – that the student individually takes the first steps towards mastering a particular learning objective. The student takes these 'first steps' where and when he/she wishes (i.e. a-synchronously) by working digitally in the adaptive tool. The student practices with the learning materials per learning objective by reading texts, watching animations, and answering questions. With these 'first steps', the student eventually reaches Bloom's third level ("*apply*") with respect to the learning objective (see Figure B) by him(her)self. Whether and how quickly the student reaches Bloom's third level (Bloom et al., 1956) is calculated by an algorithm that is included in ABC's software.

The outcome of the algorithm is influenced by the number of attempts the individual student needs to correctly answer questions as well as the complexity of a given question. The teacher guides the student to (at least) the fourth Bloom level ("*analysing*") during the synchronous learning activities (e.g. on campus lectures or workshops). To this end, various work formats are deployed, such as integration cases, discussion groups about current news items or group presentations.

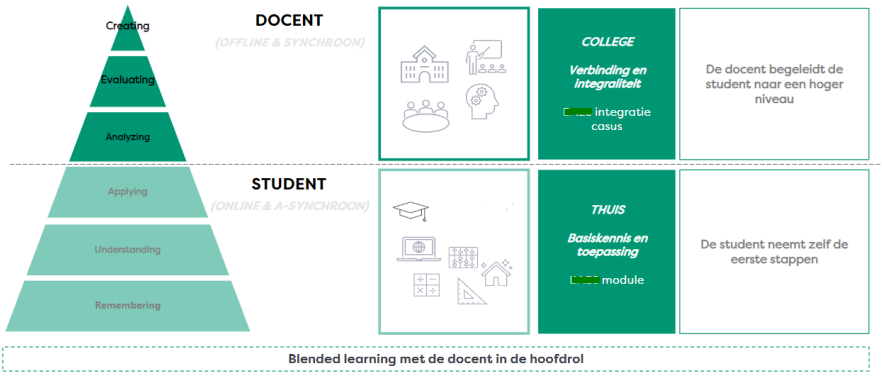

Figure B: Bloom's levels in relation to the "blended wave" and the deployment of the ALT

For a student, ABC's software includes the following components:

- Adaptive question module (arranged per learning objective);
- Instant feedback on answers given in the question module;
- Theory (also downloadable) related to a learning objective as well as animations of and sample questions about that theory;
- Insights into own level, answer attempts and activity;
- Practical tests;
- Asking questions to the teacher and giving feedback on the material in the module.

For a teacher, ABC's software includes the following components:

- Creating and managing classes;
- Gaining insight into level and progress of the (students in the) class through the teacher dashboard (see Figure C for a fictitious example);
- Creating teacher materials, such as newspaper articles and self-developed in-depth questions or (integration) case histories;
- Going through the lesson material in 'student mode';
- Creating, opening and analysing (practice) tests;
- Responding to questions or feedback from students.

Figure C: Snapshot (fictious) of the ALT's teacher dashboard

The teacher dashboard includes the "ABC score". This is a grade number (1-10) that shows a student's (or class's) progress per learning objective and across all learning objectives. The ABC score can be increased, according to the aforementioned algorithm, by answering questions in the module correctly (or decreased in case of an incorrect answer). In maximally four steps, the student receives feedback on his wrong answer attempts to instantly help the student in the learning moment. The ABC score is also disclosed to a student.

Appendix B - Trace Data Explanation

The original data file contains the following columns:

- Student id (number; student's full identity is known by ABC, not by the researchers);
- Question id (number);
- Learning objective[1] id (number; xxx);
- Learning objective sequence id (number; 1-12);
- Type of question (e.g. multiple choice or table question);
- Complexity of the specific question (number; 1-5);
- Time stamp start of answering the specific question;
- Time stamp end of answering the specific question;
- Answer(s) provided by the student to the specific question (text; all answer attempts are captured in one cell in the original data file);
- Question-answer id (number).

Each row in the data file represents a specific student's activity, i.e. answering a specific question in the question module. The student has a maximum of four (scaffolded) attempts to answer a question correctly. All answers attempts were logged in the same row.

A number of adjustments were made to the original data file:

- Split from one to four columns to capture the student's answer attempts to the specific question (text);
- Addition of the following columns:
  - Count (number; 1-4) of the answer attempts to the specific question;
  - Counter id (number) per row;
  - The day of the week (Monday - Friday) the specific student has a classroom lecture (synchronous learning activity);
  - Calendar week (number) of the student's activity in the question module;

[1] A learning objective represent a certain topic in the area of Business Economics, e.g. a company's balance sheet.

- Teaching week (number) of the student's activity in the question module;
- Day of the week (Monday - Sunday) the student was active in the question module;
- Time spent (in minutes) for answering the specific question;
- ABC score (grade; 1-10) as a result of answering the specific question. The ABC score is presented per learning objective and overall;
- Result (grade; 1-10) of the written exam taken in the ninth week.

In this course, 273 students were enrolled. Since our unit of analysis is the execution of a blended course design, it was decided to include in the scope of the data analysis only those students that were able to actually undergo the blended wave of independent (online) preparation (a-synchronous) and classroom attendance (synchronous, usually in a group of 28-32 students). We therefore filtered out students that were not assigned to a class group.