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Personalised learning networks in the university blended learning context

Redes de aprendizaje personalizadas en contextos universitarios de aprendizaje semipresencial

Dr. Feifei Han is Research Fellow in the Office of Pro-Vice-Chancellor (Arts, Education and Law Group) at the Griffith University (Australia) (feifei.han@griffith.edu.au) (https://orcid.org/0000-0001-8464-0854)
Dr. Robert Ellis is Full Professor and Dean of Learning and Teaching (Arts, Education and Law Group) at the Griffith University (Australia) (r.ellis@griffith.edu.au) (https://orcid.org/0000-0002-8781-3316)

ABSTRACT
In researching student learning experience in Higher Education, a dearth of studies has investigated cognitive, social, and material dimensions simultaneously with the same population. From an ecological perspective of learning, this study examined the interrelatedness amongst key elements in these dimensions of 365 undergraduates' personalised learning networks. Data were collected from questionnaires, learning analytics, and course marks to measure these elements in the blended learning experience and academic performance. Students reported qualitatively different cognitive engagement between an understanding and a reproducing learning orientation towards learning, which when combined with their choices of collaboration, generated five qualitatively different patterns of collaboration. The results revealed that students had an understanding learning orientation and chose to collaborate with students of similar learning orientation tended to have more successful blended learning experience. Their personalised learning networks were characterized by self-reported adoption of deep approaches to face-to-face and online learning; positive perceptions of the integration between online environment and the course design; the way they collaborated and positioned themselves in their collaborative networks; and they were more engaged with online learning activities in the course. The study had significant implications to inform theory development in learning ecology research and to guide curriculum design, teaching, and learning.

RESUMEN
En la Educación Superior, pocos estudios han investigado simultáneamente las dimensiones cognitivas, sociales y materiales de una misma población. Desde una perspectiva ecológica del aprendizaje, este estudio examina la interrelación entre elementos clave a partir de estas dimensiones en las redes personalizadas de 365 estudiantes. Los datos procedentes de cuestionarios, análisis de aprendizaje y calificaciones del curso permiten considerar estos aspectos en la experiencia de aprendizaje y en el rendimiento académico. Los participantes registraron niveles cualitativamente dispares en el nivel de implicación en el curso, oscilando de un enfoque orientado a la comprensión a enfoques basados en la reproducción de contenidos, lo que, junto a sus opciones de colaboración, generó cinco patrones distintos. Los resultados revelaron que una orientación más comprensiva y una cooperación con estudiantes de orientaciones similares tiende a asociarse con mejores rendimientos en el aprendizaje semipresencial. Sus redes personalizadas se caracterizaron por enfoques más profundos hacia el aprendizaje presencial y virtual; percepciones positivas hacia la integración de ambos contextos; el diseño del curso, por la forma y modo de colaboración; y por una mayor implicación en las actividades en línea. El estudio tuvo implicaciones significativas de aplicación en el desarrollo teórico de la investigación en la ecología del aprendizaje, así como en la forma de guiar el diseño del currículum, la práctica docente y el aprendizaje.

KEYWORDS | PALABRAS CLAVE
Ecological perspective, personalised learning network, interrelatedness, cognitive dimension, social dimension, material dimension, blended learning experience, university students.
Perspectiva ecológica, red de aprendizaje personalizada, interrelación, dimensión cognitiva, dimensión social, dimensión material, experiencia de aprendizaje semipresencial, estudiantes universitarios.

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1. Introduction

In contemporary Higher Education, students are increasingly given choices in their learning processes: the subjects they choose to study, the lectures they prefer to attend or view online, the approaches they favor when learning in a seminar, the ways in which they learn online, their partners for laboratory work, or their preference to study in a physical library or log onto an online database. Consequently, modern experiences of learning at the university level should be understood in terms of contemporaneous decisions made by students when they engage in different dimensions in their learning. In this study, we argue that each choice made by students can be considered as an element in relation to a personalised learning network, which can have different levels of success. The purpose of the study is to explain why some personalised learning networks are relatively more or less successful. Adopting an ecological perspective on student experience of learning, which looks for associations across multiple dimensions, this study examines: 1) Qualitative differences in first-year science students' personalised learning networks created by their decisions involving approaches to, and perceptions of learning, their choices of collaboration with others, and the extent of engagement with learning technologies in and outside of class in a human biology subject designed as a blended course; 2) How these choices are related to their academic performance in the course.

1.1. An ecological perspective on learning

The term "ecology" is used to describe the dynamic interactions between organisms and their environments in which a diversity of factors is intricately intertwined (Ellis & Goodyear, 2019). When the ecological metaphor is applied to learning, Barron (2006: 195) defines a learning ecology as: "the set of contexts found in physical or virtual spaces that provide opportunities for learning. Each context is comprised of a unique configuration of activities, material resources, relationships, and the interactions that emerge from them." Likewise, Jackson (2013: 2) describes an individual's learning ecology as one that: "Comprises their process and set of contexts and interactions that provides them with opportunities and resources for learning, development and achievement. Each context comprises a unique configuration of purposes, activities, material resources, relationships and the interactions and mediated learning that emerge from them". These two definitions share some similarities that learning is seen as a dynamic system from an ecological perspective, and such an ecosystem of learning is constituted by the interdependencies between learners and their intertwining with people and multifarious material resources (Ellis & Goodyear, 2019). To date, only limited research has adopted ecological perspectives in the study of learning. Of these limited studies, the majority has been conducted in school settings (Barron, 2004; Barron, Wise, & Martin, 2013). One of the limitations of these studies has been the use of a single method —either the survey or the observational method— failing to provide a more comprehensive picture of students' learning ecologies than could be obtained by using multiple methods. This study fills these gaps as it investigates ecologies of university students' learning experience by adopting complementary methods drawing on different data sources. From the definition that learning ecologies are seen as the interdependencies between learners and their intertwining with people and things, we considered three dimensions in students' learning experience, namely cognitive, social, and material. While the cognitive dimension is primarily concerned with learners' internal states, which are interdependent on other learners and non-human elements in learning, the latter two focus on the social and material dimensions respectively.

For analytical purposes, we selected the key elements in each dimension: including approaches to, and perceptions of, learning (cognitive dimension); with whom and how to collaborate (social dimension); and engagement with learning technologies both in and outside formal classes (material dimension). Investigation of the interplay of these elements across the dimensions will be able to reveal features of relatively more or less successful personalised learning networks, providing important actionable knowledge for educators to improve student learning experience. In successful personalised learning networks, we hypothesise that the elements are aligned and coherent, which tend to support student understanding of subject matter and assist them achieving desirable learning outcomes. In impoverished networks, students may miss key elements in learning, or the elements are likely to be fragmented and unaligned. Such experiences will impede understanding and be related to poorer academic performance.

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Investigating variations across multiple dimensions of student experience will provide holistic evidence that reveals structural features of successful personalised learning networks for the purposes of learning improvement. The rationale of adopting an ecological perspective includes the following:

- It acknowledges that the reality that university student learning experiences are made up of multiple elements in many dimensions and the interplay between them, which are dynamic, hard to separate, and intricately intertwined. Hence, it is only through investigation of the interrelatedness amongst them that one can explain why some students are more successful than others.
- It allows for a synergy of complementary research methodologies so that the complexity of modern learning experiences across class and online contexts can be effectively revealed.
- It accommodates a combination of different data sources, including self-report and observational data in order for triangulation of research results.

Informed by this rationale, the study draws on methodologies in three areas: 1) Student approaches to learning (Pintrich, 2004; Prosser & Trigwell, 2017); 2) Social network research (De-Nooy, Mrvar, & Batagelj, 2011; Wasserman & Faust, 1994); 3) Materiality in learning (Fenwick, 2015; Fenwick & Landri, 2012). A combined use of these methods is illuminating because: 1) Their explicit and implicit intent to reveal qualitative variations when used to investigate student learning; 2) Their capacity to examine student learning experience at the individual and group levels across face-to-face and online contexts; and 3) they are consistent with an ecologically informed, social scientific way to understanding student learning experience adopted in this study.

> **From the definition that learning ecologies are seen as the interdependencies between learners and their intertwining with people and things, we considered three dimensions in students' learning experience, namely cognitive, social, and material.**

1.2. Student approaches to learning (SAL) research

SAL research is used in this study to identify key cognitive elements in student learning experience to explain qualitatively different academic performance in Higher Education (Kember, 2015). Seminal studies have shown that how students go about learning (their approaches) and how they perceive learning (their perceptions) relate to their learning performance (Entwistle & Ramsden, 2015).

Applying the framework in blended learning context, research has demonstrated logical associations amongst approaches to face-to-face and online learning and perceptions of blended learning environment: students who perceive that face-to-face and online learning are well integrated tend to adopt deep approaches to learning and to using online learning technologies, which in turn are positively associated with better academic achievement (Ellis, Pardo, & Han, 2016). These deep approaches are proactive, engaged, reflective, and analytical, which help to achieve meaningful understanding of the subject matter (Nelson Laird, Seifert, Pascarella, Mayhew, & Blaich, 2014). When students do not see the relevance between face-to-face and online learning, they are more likely to approach learning on a surface level, thereby obtaining relatively poorer performance (Ellis & al., 2016).

Surface approaches involve adopting simplistic learning strategies, relying heavily on formulaic and mechanistic ideas to merely fulfill the required tasks and to pass exams (Vermunt & Donche, 2017). The cognitive elements investigated in this study are student approaches to face-to-face and online learning and their perceptions of the blended learning environment.

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1.3. Social network research

Originating in sociology, social network research aims to identify, detect, and interpret roles of individuals within a group and patterns of ties amongst individuals (De-Nooy & al., 2011; Wasserman & Faust, 1994). Social network research in education has investigated work and discussion ties amongst teachers (Quardokus & Henderson, 2015), characteristics of formal and informal interactional networks amongst students (Cadima, Ojeda, & Monguet, 2012), the relation between friendship ties and learning outcomes (Brewe, Kramer, & Sawtelle, 2012; Rienties, Héliot, & Jindal-Snape, 2013), students' online communications (Rodríguez-Hidalgo, Zhu, Questier, & Alfonso, 2015), and the associations between learning networks and achievement (Tomás-Miquel, Expósito-Langa, & Nicolau-Julia, 2015).

The current study will investigate the relations between students' approaches to learning, perceptions of the blended learning environment, and quality of collaborations, because of limited extant research. The key social network measures of student collaborations will serve as indicators of social elements in student learning experience.

1.4. Materiality in learning

Research into materiality in learning experience focuses on a combined unit of analysis of "people and things" (artefacts), and how their combination helps to create, consolidate, and disseminate knowledge (Fenwick, 2014). Informed by social constructivism, this body of research challenges the isolated role of human factors and foregrounds things in the learning (Fenwick, 2014).

Hence, objects, things, and artefacts are not considered as merely having meanings attributed to by humans. Instead, they are treated as "continuous with and in fact embedded in the immaterial and the human" (Fenwick, Nerland, & Jensen, 2012:6). This area of research has been used to explore how learning is experienced through learner configurations, tangible and intangible objects, such as learning tasks in class and online (Ellis & Goodyear, 2019). In this study, students' use of online learning technologies is considered an element of the material dimension of their learning experience.

1.5. Research questions

Three research questions guided the current study:

1) What are the relations between cognitive elements of learning experience and academic performance?

2) What are the relations between cognitive and social elements of learning experience and academic performance?

3) What are the relations amongst cognitive, social, material elements of learning experience and academic performance?

2. Material and method

2.1. Participants

Altogether 365 first-year undergraduates (251 females, 113 males; ages: 18 to 53, M=19.72, SD=3.55) from a metropolitan Australian university were recruited following the university ethics guidelines. They were enrolled in a semester-long blended course – introduction to human biology. They were from faculties of health sciences (162), nursing (22), pharmacy (55), and sciences (124) (two students did not report faculty information.

2.2. Learning context

The face-to-face teaching in the course included a weekly two-hour lecture, a three-hour laboratory class every fortnight, and a two-hour workshop every other week. The online learning required 6 to 9 hours' participation in the weekly activities and collaboration. An important learning goal in the course was to develop students' teamwork and collaborative skills, which was promoted by encouraging students to work in small groups to conduct experiments in the laboratory and to co-write scientific reports in the workshops. The course not only required students to learn disciplinary contents, but it also aimed to develop graduate skills, including inquiry abilities, critical and creative thinking, and collaborative skills.

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2.3. Data sources and instruments

The data came from four sources: 1) A 5-point Likert-scale questionnaire interrogating approaches to, and perceptions of, learning (cognitive elements); 2) A social network questionnaire interrogating students' collaboration (social elements); 3) Online learning analytics measuring frequency and time of students' interactions with the online learning technologies (material elements); 4) The final marks (students' academic performance).

2.3.1. The Likert-scale questionnaire

The development and validation of the scales in the questionnaire has been reported in previous studies (Bliuc, Ellis, Goodyear, & Piggott, 2010; Ellis & Bliuc, 2016; Han & Ellis, 2019a), which confirmed the reliability and validity. The items pool was constructed by drawing on interviews with students and consulting with the SAL literature and previous questionnaires using the SAL framework (Biggs, Kember, & Leung, 2001; Crawford, Gordon, Nicholas, & Prosser, 1998). Item analysis, exploratory factor analysis, scale reliability analysis, confirmatory factor analysis, and invariance tests have been used for validating the scales (Han & Ellis, 2019a).

- "Deep approaches to inquiry" scale (DAI: 5 items; α=.71) describes that approaches to learning through inquiry are characterized being proactive, initiative, and independent, with deep thinking to pursue a line of inquiry (e.g., "I often pursue independent pathways when researching something").
- "Surface approaches to inquiry" scale (SAI: 4 items; α=.63) are approaches that lack thinking, being simplistic and mechanistic, and are heavily dependent upon others (e.g., "Researching something for a task means only using the resources given to me by the teacher").
- "Deep approaches to online learning technologies" scale (DAT: 5 items; α=.72) assesses using technologies as a way to promote deeper understanding of the key ideas, to facilitate research, to connecting concepts in the course to real-world problems (e.g., "I spend time using the learning technologies in this course to connect key ideas to real contexts").
- "Surface approaches to online learning technologies" scale (SAT: 4 items; α=.66) describes using online learning technologies to a limited extent, and using them as just to satisfy course requirements rather than to promote learning (e.g., "I only use the learning technologies in this course to fulfil course requirements").
- "Perceptions of integrated learning environment" scale (INTER: 6 items; α=.88) evaluates to what extent students' perceptions of face-to-face (e.g., lectures, ideas, and key concepts presented face-to-face) and online learning (e.g., online resources, course website, online activities) are coherent and integrated (e.g., "The online activities help me to understand the lectures in my course").

2.3.2. The social network questionnaire

The social network questionnaire examined students' choices of collaborators and mode of collaborations. Students were asked to name up to three peers according to frequency of collaborations in this course; and to indicate the mode of collaborations.

Please list up to three students you collaborated in this course according to frequency, and circle the mode of collaboration (F=face-to-face, B=both face-to-face and online): The most frequent: F-B; The second most frequent: F-B; The third most frequent: F-B.

2.3.3. The online learning analytics

The online learning analytics included frequency and time spent on online learning resources and interactive activities. The online learning resources, which included course timetable, learning objectives and learning outcomes, reading materials, video lectures, lecture notes, and digital images, provided sufficient scaffolding and materials.

The online interactive activities included multiple-choice questions, labeling, matching, text entry, short answer questions, biological card games, and these components offered opportunities to interact with biological concepts and receive feedback on their responses.

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2.3.4. The final marks

The final marks (ranged from 32 to 90, M=67.93; SD=10.13) were aggregated scores of six assessments: 1) Summative quizzes for laboratory sessions (15%); 2) Oral presentation of a case study (8%); 3) Online posts following each workshop (3%); 4) Peer feedback for scientific report drafts (4%); 5) Final scientific report (20%); 6) Final examination (50%).

Except for peer feedback, all the assessments were graded by the teaching staff. The final examination consisted of multiple-choice questions based on the learning materials from the course.

2.3.5. Data collection

The questionnaires were completed in class towards the end of the semester. Students were ensured that once their responses to the questionnaire were matched with the online learning analytic data and their final marks, unique codes would be assigned to replace their names in the data analyses.

2.3.6. Data analysis

To answer the first research question, correlation, cluster analysis, and one-way ANOVAs were performed. While correlation analyses examined pairwise relations, cluster analysis and one-way ANOVAs revealed interrelations amongst groups of variables. To answer the second research question, social network analysis (SNA) were applied using Gephi, which visualized collaborative patterns and calculate key SNA measures, including *degree*, eccentricity, average clustering coefficients, and *eigenvector* (Bonacich, 2007).

The SNA measures across different collaborative patterns were then compared using one-way ANOVAs. To provide the answer to the third research question, one-way ANOVAs and post-hoc analyses were conducted to examine the frequency and time spent on learning technologies amongst qualitatively different collaborative patterns jointly shaped by students' choices in the cognitive and social elements.

3. Results

3.1. Results for research question 1

The results of correlation analyses are presented in Table 1, which shows that DAI was positively and moderately correlated with DAT (r=.22, p<.01), INTER (r=.34, p<.01), and final marks (r=.23, p<.01). DAI was moderately and negatively associated with SAI (r= -.41, p<.01) and SAT (r=-.29, p<.01). SAI had positive association with SAT (r=.28, p<.01), but negative association with DAT (r=-.14, p<.01), and INTER (r=-.13, p<.01).

Table 1. Correlation analysis results

Variable	DAI	SAI	DAT	SAT	INTER
SAI	-.41**				
DAT	.22**	-.14**			
SAT	-.29**	.28**	-.46**		
INTER	.34**	-.13**	.61**	-.44**	
Final marks	.23**	-.10	-.05	-.04	-.01

DAT was moderately and negatively related to SAT (r=-.46, p<.01), but it positively associated with INTER (r=.61, p<.01). The INTER, however, was negatively related to SAT (r=-.44, p<.01). Table 2 shows that the cluster analysis produced two clusters, which had 108 and 257 students respectively.

The scores of all the variables were standardized into z-scores, which were used in the one-way ANOVAs. One-way ANOVAs showed that cluster 1 and 2 students differed significantly on all the variables: DAI ($F(1,363)=35.18$, $p<.01$, $\eta^2=.09$), SAI ($F(1,363)=75.26$, $p<.01$, $\eta^2=.17$), DAT ($F(1,363)=132.08$, $p<.01$, $\eta^2=.27$),SAT ($F(1,363)=264.69$, $p<.01$, $\eta^2=.42$), INTER($F(1,363)=126.50$, $p<.01$, $\eta^2=.26$), and final marks ($F(1,363)=4.04$, $p=.04$, $\eta^2=.01$).

Table 2. Cluster and one-way ANOVA results							
Variable	Understanding (N=108)		Reproducing (N=257)		F	P	η^2
	M	SD	M	SD			
DAI	0.45	0.87	-0.20	1.01	35.18	.00	.09
SAI	-0.63	0.74	0.27	0.97	75.26	.00	.17
DAT	0.80	0.73	-0.34	0.91	132.08	.00	.27
SAT	-1.00	0.62	0.44	0.83	264.69	.00	.42
INTER	0.79	0.65	-0.34	0.96	126.50	.00	.26
Final marks	0.23	0.79	0.03	0.93	4.04	.04	.01

Cluster 1 students reported using more DAI, DAT, and had positive ratings on INTER; which were learning oriented towards understanding of subject matter ("understanding" learning orientation); whereas cluster 2 students adopted more SAI, SAT, and had negative ratings on INTER, which were characteristics of learning towards knowledge reproducing ("reproducing" learning orientation). Understanding students achieved better academic performance than reproducing students in the course.

3.2. Results for research question 2

Using students' learning orientations (understanding vs. reproducing) and their choices of collaboration (alone, collaborating with students from the same cluster, collaborating with students from a different cluster), five collaborative patterns were identified:

- Understanding Alone (UA) students had an understanding orientation but did not collaborate;
- Reproducing Alone (RA) students had a reproducing orientation but did not collaborate;
- Understanding Collaboration (UC) students had an understanding orientation and collaborated with understanding students;
- Reproducing Collaboration (RC) students had a reproducing orientation and collaborated with reproducing students;
- Mixed Collaboration (MC) students only collaborated with students having a different orientation from them.

Table 3. SNA descriptive statistics						
Descriptive statistics	Whole Network	UA	UC	MC	RC	RA
No. of students	365	61	40	56	120	88
No. of collaborations	189	0	25	79	85	0
No. of blended mode of collaborations	238	0	28	31	72	0

The visualization and the descriptive statistics of the five groups of students showing five collaborative patterns are presented in Figure 1 and Table 3 respectively.

Table 4. One-way ANOVAs results on the SNA measures								
SNA measure	Group	M	SD	F	p	η^2	Post-hoc (effect size: Cohen's d)	
Degree	UC	1.98	0.70	11.24	.00	.10	UC>MC	(0.97)
	MC	1.36	0.59				UC=RC	(0.16)
	RC	1.86	0.80				RC>MC	(0.68)
Eccentricity	UC	1.78	1.37	1.38	.25	.01	---	---
	MC	1.61	0.85				---	---
	RC	1.92	1.21				---	---
Average clustering coefficient	UC	0.58	0.48	9.19	.00	.08	UC>MC	(0.86)
	MC	0.19	0.36				UC>RC	(0.43)
	RC	0.38	0.46				RC>MC	(0.42)
Eigenvector	UC	0.19	0.22	8.71	.00	.08	UC>MC	(0.86)
	MC	0.06	0.07				UC=RC	(1.00)
	RC	0.17	0.20				RC>MC	(0.65)

To compare the quality of students' collaborations amongst the groups, one-way ANOVAs were applied on the key SNA measures. As the SNA measures were only available for students who collaborated, the analyses were conducted amongst UC, MC, and RC, and the results are displayed

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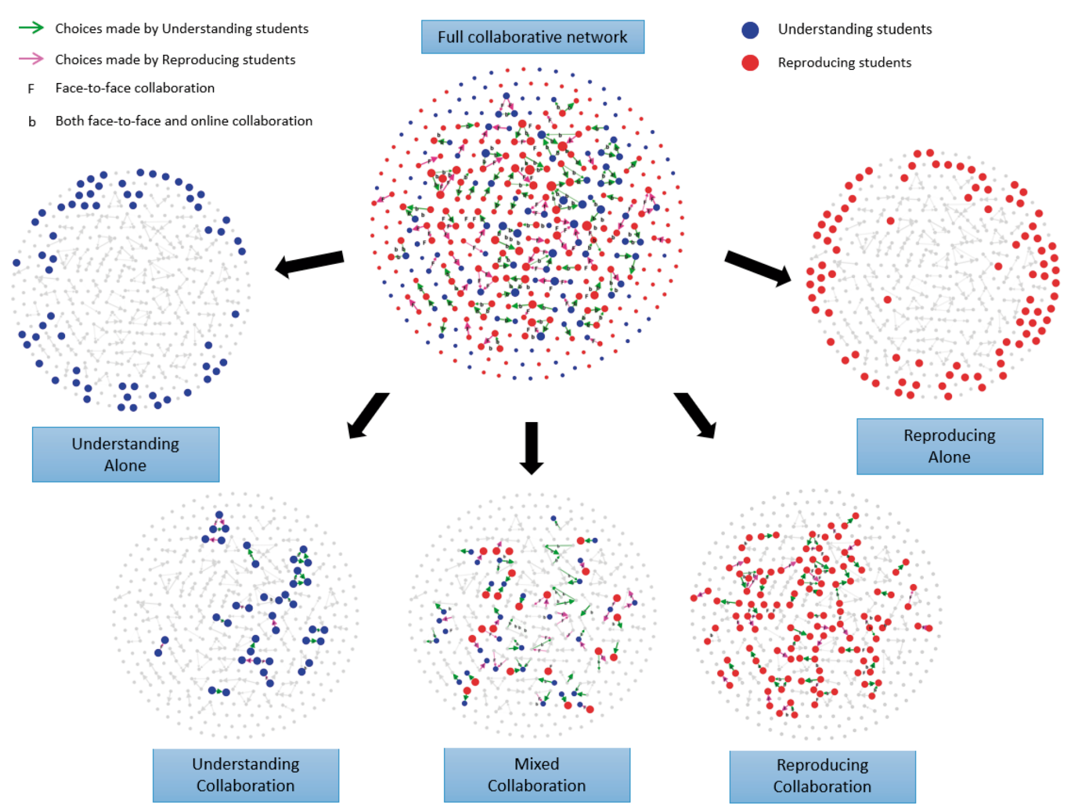
in Table 4. This table shows that the three groups of students differed significantly on degree (F(2,214)=11.24, p<.01, η^2=.10), average clustering coefficient (F(2,214)=9.19, p<.01, η^2=.08), and eigenvector (F(2,214)=8.71, p<.01, η^2=.09).

The LSD post-hoc analyses showed that for the degree, UC and RC students had more collaboration than MC students. UC students had a higher clustering coefficient than RC students, who in turn were higher than MC students. This suggests that UC students were more likely to form closely knitted sub-networks than RC and MC students, hence they had more opportunities to directly interact with all the members in the sub-networks.

Both UC and RC students had higher eigenvector than MC students, demonstrating that UC and MC students were surrounded by others with higher quality of collaborative connections.

Figure I. Full collaborative network and five collaborative patterns



3.3. Results for research question 3

The comparison of the use of learning technologies amongst the five groups revealed the material elements of learning experience in relation to the cognitive and social elements and their academic performance, because the five groups of students representing five collaborative patterns were jointly shaped by the cognitive and social elements as well as their learning performance. Table 5 shows that the five groups differed significantly in their frequency of using online learning resources (F(4,361)=2.50, p<.05, η^2=.03), online interactive activities (F(4,361)=2.63, p<.05, η^2=.03), and the total time online (F(4,361)=2.50, p<.05, η^2=.03). The LSD post-hoc analyses found that UC students engaged with online learning more frequently than the other four groups, except for the frequency of access to online interactive activities. There was no difference between UC and MC students. UC students also spent more time online than RC and RA students.

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Variable	Group	M	SD	F	p	η^2	Significant post-hoc (effect size: Cohen's d)	
Online learning resources	UA	20.72	17.60	2.50	.03	.03	UC>UA	(0.55)
	UC	35.00	35.40				---	---
	MC	22.98	27.61				UC>MC	(0.39)
	RC	19.92	24.60				UC>RC	(0.55)
	RA	21.08	28.94				UC>RA	(0.45)
Online interactive activities	UA	44.80	32.69	2.63	.04	.03	UC>UA	(0.50)
	UC	65.74	53.72				---	---
	MC	48.09	55.62				UC=MC	(0.01)
	RC	41.22	40.30				UC>RC	(0.16)
	RA	41.64	44.57				UC>RA	(0.14)
Time online	UA	94.19	158.96	2.50	.03	.03	UC=UA	(0.20)
	UC	124.54	140.35				---	---
	MC	102.38	193.27				UC=MC	(0.13)
	RC	64.42	96.28				UC>RC	(0.55)
	RA	62.55	88.67				UC>RA	(0.58)

Table 5. One-way ANOVAs results on use of learning technologies

4. Discussion and conclusion

Before discussing important implications for an ecological perspective to understanding the complexity of student learning experience in blended contexts in contemporary Higher Education, some limitations are noted. The study was conducted in a science course and the participants all majored in sciences and applied sciences. The relations amongst cognitive, social, and material dimensions in their learning experience may differ from humanities and social sciences students. Before strong conclusions are drawn, similarly designed studies in a range of disciplines are warranted. Despite these limitations, the use of different types of data (self-report and observational) and evidence derived from the multiple methodologies offer some valuable insights.

From an ecological perspective on learning, this study investigated personalised learning networks of 365 first-year undergraduates in a blended course. Personalised learning networks on the university student experience emphasizes the value of an ecologically inspired approach to research into learning. The distinction between this type of investigation and closely related previous investigations is a foregrounding of measures of collaborations and materiality in student experience to complement the findings in the cognitive dimension. One of the key shifts in the methodologies used is the unit of analysis comprising both people and things, including measures of their interplay. In this study, we bring together multiple complementary methods from SAL research, social network research, and materiality in learning, to reveal the choices and decisions made by individuals and groups of students in their learning experience. Broadly summarizing, students of the most successful learning experience were UC students, as they not only performed relatively better in learning the contents of the subject matter, but they also developed their collaborative skills, an important attribute required for graduates to be ready for future employment. Apart from obtaining higher academic performance, these students reported deep approaches to learning in class and online, held positive perceptions of the integration of the learning environment, used effective strategies for collaboration, and were more engagement with learning technologies. The following explains in more details of qualitative variations amongst the elements in these three dimensions.

In terms of qualitative variations of cognitive dimension, we identified students reporting contrasting learning orientations described as "understanding" and "reproducing". "Understanding" students reported using deep approaches to face-to-face and online learning and holding positive perceptions of the integrated learning environment. They performed academically higher in the course compared to "reproducing" students, who reported using surface approaches and holding relatively negative perceptions of how the online part of the experience was integrated into the course design. They obtained relatively lower academic outcomes. These results are consistent with previous SAL research in different academic disciplines, such as engineering (Ellis & al., 2016), business (Han & Ellis, 2019b), and social sciences (Bliuc & al., 2010) in the blended learning settings that there is a logical alignment amongst approaches to learning, perceptions of learning environment, and academic performance. Our results and the similar previous results together seem to suggest that across disciplines distinctive learning orientations are present based on students' contrasting approaches to and perceptions of learning, highlighting the importance of the approaches and perceptions elements.

The variations in the cognitive dimension combined with students' choices of collaboration revealed qualitative variations in the social dimension of student learning experience. The five identified groups demonstrated students' collaborative experience with varying success: two groups chose not to collaborate (UA and RA) and three did collaborate (UC, RC, and MC). UA and RA students failed to fulfil one of the key course aims of developing teamwork and collaborative skills as an important graduate attribute. Amongst the three collaborative groups, UC students appeared to have more successful collaborative experience. They collaborated more (degree); their collaborative sub-networks tended to be closely knitted, which means that they might have more opportunities to contact directly with each member in the sub-networks (average clustering coefficient); and their neighborhood students (the students whom they directly connected to) were also well-connected in other sub-networks (eigenvector). Together, these findings suggested that UC students not only maximized their opportunities to develop collaborative skills, but also were in a position, which allowed them to gather more information and share knowledge more easily in the class compared with MC and RC students.

Looking at the elements in the material dimension, in general UC students were more engaged with the online learning activities than the other students. This was reflected by the observed evidence of their use of learning technologies. These observations of students' actual use of learning technologies not only demonstrated significant differences in student choice of material dimension, but its consistency with students' self-report evidence triangulates the results and reinforces the overall findings.

The results generated by different data sources and multiple methods across the three dimensions describe key aspects of students' personalised learning networks in their learning ecologies. These unique configurations manifested by students' decision-making processes in learning suggest how complex a learning ecology can be in a blended course design: that multifarious resources, such as people, tangible things, and virtual learning space and learning activities, are drawn and orchestrated in order to learn (Ellis & Goodyear, 2019).

The study offers some theoretical implications. The authors do not delude themselves that this is the first time the idea of an ecological perspective on learning research has been undertaken (Barnett, 2018; Cope & Kalantzis, 2017; Patterson & Holladay, 2017). However, it is the first time that complementary multiple methodologies have been brought to bear on the same population sample producing consistent results in ways that help to push onwards an ecologically informed theory of learning in higher education. The strengths of the study are: 1) its inclusion of both human and non-human elements in student blended learning experience; 2) its adoption of multiple and complementary methods, which allowed structural discovery of qualitative variations of students personalized learning networks that distinguished on the key elements across major dimensions in learning; and 3) its simultaneous use of self-report and observational data sources provides a more holistic understanding of the nature of overall student experience than collecting data from a single source. These methodological merits can be applied in the ecological theory of learning to continuously identify and expand key elements and dimensions in university students' blended learning experience in order to better explain factors impacting on student academic success.

Our fine-grained analyses in and across each dimension also provide specific actionable evidence for teachers so that corresponding strategies can be undertaken in the following ways. The identification of less desirable student learning orientations ("reproducing") early in course delivery can help teachers design activities to encourage students to adjust surface approaches and negative perceptions of the online context. This could be achieved through inviting "understanding" students to talk about their ways of approaching learning, and the strategies when engaging with learning technologies. Teachers could also explicitly discuss the purpose of online activities in terms of course outcomes, so that students can appreciate the coherence between face-to-face and online components in the course. These strategies may increase student engagement both in class and online.

Similarly, to promote collaboration in learning, the identification of the five groupings of students in the course can help teachers understand why not all students develop collaborative skills. Teachers could fruitfully discover these types of groupings amongst their students in order to pair them. For instance, teachers can consider assigning students who are not likely to collaborate into those collaborative groups (UC, MC, and RC groups). Likewise, teachers could mix UC students with RA and RC students so that all collaborative groups have at least one or two stronger partners.

The university student experience of learning in the current Higher Education context is growing in complexity through new pedagogies and new technologies across a variety of learning contexts. With rapid changes continually occurring, more research is required that reveals how elements across cognitive, social, and material dimensions of the student experience are related to each other and to learning outcomes.

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