NONLINEAR LEARNING PATH: A SYSTEMATIC REVIEW

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Received: 26/08/2023 **Accepted:** 12/02/2024

ABSTRACT

Students benefit from a nonlinear learning path, also known as a nonsequential learning path, because it allows them to control the pace and sequence of their learning. However, the dynamics of a nonlinear learning path, particularly within an open learning environment like MOOCs, remain underexplored. The current study aims to map out various nonlinear learning paths and explore the potential for personalisation within these environments. Guided by the PRISMA 2020 Statement, we conducted a comprehensive review of 3,418 articles from three databases, focusing on 30 that were relevant to nonlinear learning paths in open learning environments. We discovered that a nonlinear learning path in MOOCs involves path selection, cyclical paths, or skipped paths, all influenced by the design of the MOOC learning materials. In classrooms utilizing an open learning environment, a nonlinear learning path is facilitated by activities such as face-to-face or online discussions, self-study materials, student-created content, project mentoring or coaching, peer feedback, and co-learning activities. Additionally, personalisation, tailored by educators or technology, is key to preventing students from becoming disoriented within these open learning environments. Our findings highlight the importance of promoting nonlinear learning paths in both classrooms and MOOCs, developing learning path recommender systems, and creating supportive MOOC learning materials. Future research should explore students' perceptions of nonlinear learning paths within an open learning environment, particularly focusing on the integration and impact of MOOC learning materials.

Keywords: MOOC learning materials, MOOC personalisation, nonsequential learning path, open learning environment, personalized learning path.

INTRODUCTION

The market value of e-learning is expected to reach $645 billion by 2030, continuing its rapid expansion (Straits Research, 2022). The number of users is also predicted to reach 0.90 billion by 2027 (Statista, 2023). The growth in this sector is driven by the rise of online learning and a trend towards personalised learning experiences (Statista, 2023; Straits Research, 2022). Personalisation has evolved from a choice to a necessity. Factors such as technology, diverse socioeconomic backgrounds, and individual knowledge and preferences are pivotal in driving this shift towards personalisation (Huang, Spector, & Yang, 2019).

Building personalised learning heavily relies on the interaction between the learner and the content (Powell & Leary, 2021). Such learner–content interaction is described as how a student gets intellectual information from the course materials (Moore & Kearsley, 2011). Although it is essential, learner–content interaction is infrequently explored compared to the learner–instructor, and learner–learner interaction (Xiao, 2017; Zimmerman, 2012). To date, learner–content interaction has been studied based on the interaction categories and duration of engagement (Majumdar, Flanagan, & Ogata, 2021), motivation and access activity (Le et al., 2022), textbook or e-book features (Day & Pienta, 2019), measurement tools (Powell & Leary, 2021), and learning path (Premlatha & Geetha, 2015). The term '*learning path*' itself refers to the sequence of learning materials (Rahayu, Ferdiana, & Kusumawardani, 2023).

Viewing the learning path as an information flow, from start to finish, highlights the importance of the learner-content interaction. This perspective results in two types of learning paths: linear and nonlinear. The linear path involves studying topics sequentially (topic 1, then topic 2, and so on). In contrast, nonlinear learning allows students to choose the order of topics, facilitating a nonsequential approach to learning (Robberecht, 2007).

Nonlinearity in learning does not eliminate the need for structured materials, as a lack of structure means no learning (Rootzen, 2015). However, the growth of nonlinear learning, driven by the demands for personalisation and advanced learning materials, has revealed a significant research gap in understanding how to effectively structure learning materials using a nonlinear approach. For example, the heutagogy educational method illustrates nonlinear learning by designating two-thirds of its learning contents as 'non-negotiable,' (Hase, 2011), but the understanding of its application is under-studied. The gap is further deepened by the critical need for scaffolding -achieved through tools (Mamun, Lawrie, & Wright, 2020) or expert guidance- in personalising learning. This study aims to address these gaps by exploring nonlinear learning paths and personalisation, providing educators with practical insights for classroom use.

Nonlinear learning relies on Open Learning Environments (OLEs) to function effectively, whether in traditional classroom settings or online platforms. These environments empower students to determine what they consider important in their learning (Land & Oliver, 2012) and to navigate their own learning paths. The following are the research questions (RQs):

RQ1: How do OLEs support nonlinear learning paths?

RQ2: To what extent do OLEs enable personalised nonlinear learning paths?

The remaining sections of this paper continue as follows: Section 2 presents a theoretical background of the learning path, nonlinear learning path characteristics, and its benefits and drawbacks. Section 3 describes the research methodology using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 Statement. Section 4 presents the findings linked to the research questions, followed by Section 5, which discusses implications, the research agenda, and limitations. The final section of this paper is the conclusion and recommendation for educators.

LITERATURE REVIEW

Linear and Nonlinear Learning Paths

A learning path is a sequence of learning materials. The term '*learning path*' is also used to refer to the curriculum sequences (Iglesias, Martinez, Aler, & Fernandez, 2004; Weber, 2012), content sequences (Ros & Lizenberg, 2006), study paths (Ros & Lizenberg, 2006), and instructional sequences (Pepin & Kock, 2021).

The path can be classified from two different viewpoints. According to the *task sequence approach*, the content sequence can be divided into hierarchical, procedural, topical, spiral, and a combined sequencing approach (Cock & Meier, 2012). Hierarchical sequencing divides skills into high and low levels with subcomponent-component dependence. It means that lower-level skills must be taught before higher-level ones. Procedural sequencing promotes learning using a step-by-step approach, where each step represents a separate concept. The topical approach ensures that topics are taught at the appropriate level before progressing, while spiral sequencing involves teaching topics in recurring cycles.

Based on the *information flow*, the learning path could be classified as linear and nonlinear. A linear path is synonymous with the process of reading a printed book which begins with the first chapter, then the second one, the third one, and so forth. Educators usually use a linear approach by providing the same set of learning materials in a predetermined flow for all students in the classroom. In other words, novice, intermediate, and advanced students all start at the same point and proceed through the learning materials on the same path (Robberecht, 2007). This regularity brings many benefits for constructing comprehensive knowledge, particularly for hierarchical and procedural contents. However, linear path has drawbacks as it fails to consider each student's background, preferences, interests, and learning speed. It also does not consider that some students already know certain knowledge.

The nonlinear approach is comparable to how a person navigates a forest using a Global Positioning System (GPS) (Correa, 2017). It is also like a student randomly selecting any page in a printed textbook and then moving directly to any other page (Robberecht, 2007). However, printed books lack the ability to provide additional context for each page, hindering comprehensive learning through random reading. In contrast, online materials use hyperlink technology to facilitate connections among materials, thereby enhancing the construction of comprehensive knowledge.

Nonlinear learning integrates nonsequential access to learning materials with the use of *hyperlinks*—or simply links. Links allow users to click their way from page to page (W3Schools, n.d.). Clickable things such as text, images, and buttons are found anywhere on the internet. Without links, each piece of content will stand alone. In online learning, links also serve to enhance thinking processes and create connections and context among learning materials. These links facilitate various actions such as navigating, browsing, searching, connecting, collecting, annotating, and editing (Peters, 2002).

Learning in nonlinear paths also offers more flexibility and improves multitasking ability. This approach takes advantage of *neuroplasticity*, which is our brain's capability to adapt through growth and reorganisation. When faced with a lot of information, our brains can adjust to handling information from different sources at the same time. As a result, neuroplasticity allows us to adapt to *"simultaneous exposure to information from various sources, and this skill evolves into an enhanced capacity of nonlinear learning"* (Lucin & Mahmutefendic, 2013). In other words, learning in a nonlinear path matches our natural way of thinking, which is not straightforward but interconnected. This allows us to better understand, and link any pieces of information (Feldman, 2001).

Educators and Technology Roles in Nonlinear Learning

The implementation of nonlinear learning requires a variety of enabler roles. Educators are crucial as they design the learning structure for specific subject areas. Their roles extend beyond instruction to include empowering students (empowerer), guiding their exploration (scout), providing support (scaffolder), and assessing students' progress (assessor) (Bishop et al., 2020).

Technology can complement, substitute for, or augment several educators' roles. In the current study, we adopt the *classification of OLE tools* as processing tools, manipulation tools, and communication tools (Hannafin, Land, & Oliver, 1999; Land & Oliver, 2012). Technology, serving as processing tools, collects and processes data on learning processes and outcomes. As manipulation tools, technology helps select or assists students in choosing their learning paths. Communication tools are used to provide various learning modes and media either synchronously or asynchronously.

Personalisation is essential to mitigate disorientation in nonlinear learning and assist students in achieving students' autonomy. Based on the interaction type, personalisation can be *adaptable* or *adaptive*. Adaptable personalisation tailor's recommendations based on student's input, while adaptive approaches use inferences data drawn from student-content interactions (Van Velsen, Van Der Geest, Klaassen, & Steehouder, 2008). Examples of adaptability are guided tours or metacognitive maps (Correa, 2017), whereas adaptive personalisation could use a recommender system informed by the emotional feedback from a social network (Khaled, Ouchani, & Chohra, 2019).

In summary, personalisation can be conducted by both educators and technology (Shemshack & Spector, 2020). Educators tailor learning paths using scaffolding techniques, and technology acts as a recommender system. Figure 1 depicts the relationship between the learning paths, nonlinear learning, and personalised learning.

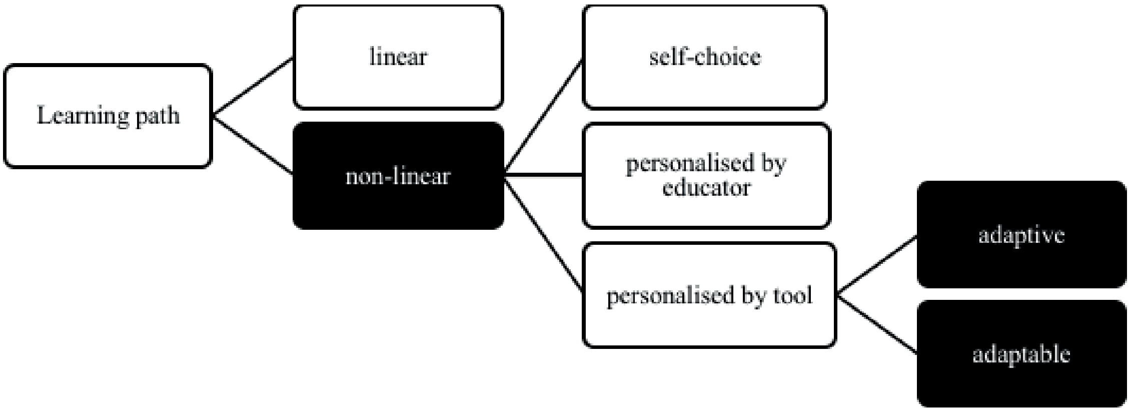

Figure 1. Relationship among learning paths, nonlinear learning, and adaptable personalised learning

RESEARCH METHOD

There are several methodologies for conducting or reporting systematic reviews, such as Methodological Expectations of Cochrane Intervention Reviews (MECIR) (Higgins et al., 2022), Methodological Expectations of Campbell Collaboration Intervention Reviews (MECCIR) (The Campbell Collaboration, 2014) and Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). One component of the PRISMA is the PRISMA 2020 Statement, which serves as the latest guideline for reporting systematic reviews. The current systematic review was reported according to the PRISMA 2020 Statement, which suggests five steps for reporting by identifying new studies via databases: (1) literature search, (2) abstract screening, (3) article retrieval, (4) eligibility assessment, and (5) data extraction (Page et al., 2021).

The current systematic review process starts with a thorough search of various databases to find relevant studies. Next, we carefully examine the abstracts of these studies to determine if they meet the inclusion and exclusion criteria. Then, we retrieve the full papers that passed the initial screening. Subsequently, articles are assessed to ensure they meet the criteria for eligibility. Finally, we conduct data extraction, where we record key information and findings from each paper.

Literature Search

This study conducts a broad automated search from the ERIC, Emerald Insight, and Scopus databases. More precisely, we searched using the keyword *'learn* AND open AND (path OR sequence OR curricul*) AND (student OR learner)'*. This initial search retrieved 3,418 records (i.e., titles and abstracts). To find matching topics, we identified studies from English-language journals within the areas of: Education, E-learning, Psychology, Social Sciences, Computer Science and Engineering. As a result, we have 1,204 abstract records to be screened.

Abstract Screening

Inclusion criteria are applied during abstract screening. This means that records must be from open learning environments, primary studies, and must discuss the learning path. Most records were excluded since they did not study the learning path. Our remaining records were 87 abstracts.

Article Retrieval

Full text retrieval was performed after the abstract screening. Fifteen records could not be obtained because we did not have any access to them. Thus, we have 72 articles left.

Eligibility Assessment

Full texts were assessed for eligibility using several exclusion criteria as below:

- Reports that describe a model or perspective (e.g., those containing opinions, explanations of the benefits of distance learning, descriptions of models, modelling based on quantitative surveys, assignments using available resources, and concept recommendations).
- Reports related to macro (n=2) or meso curriculum (n=8).
- Reports that did not delve into technical details (e.g., those lacking detailed information on personalising curriculum, lacking an explicit sequence of Open Educational Resources, or focused on educators only).
- Reports related to curriculum development (e.g., those that are case study descriptions, guided exercises, explore prerequisite relationships among resources, or focus on curriculum design without personalisation).
- Reports on quantitative studies (e.g., surveys on motivation and experiences, application reviews).
- Reports discussing task design, specifically how educators design collaborative tasks.

Finally, 30 papers were eligible for extraction. The details of the article selection are presented in Figure 2.

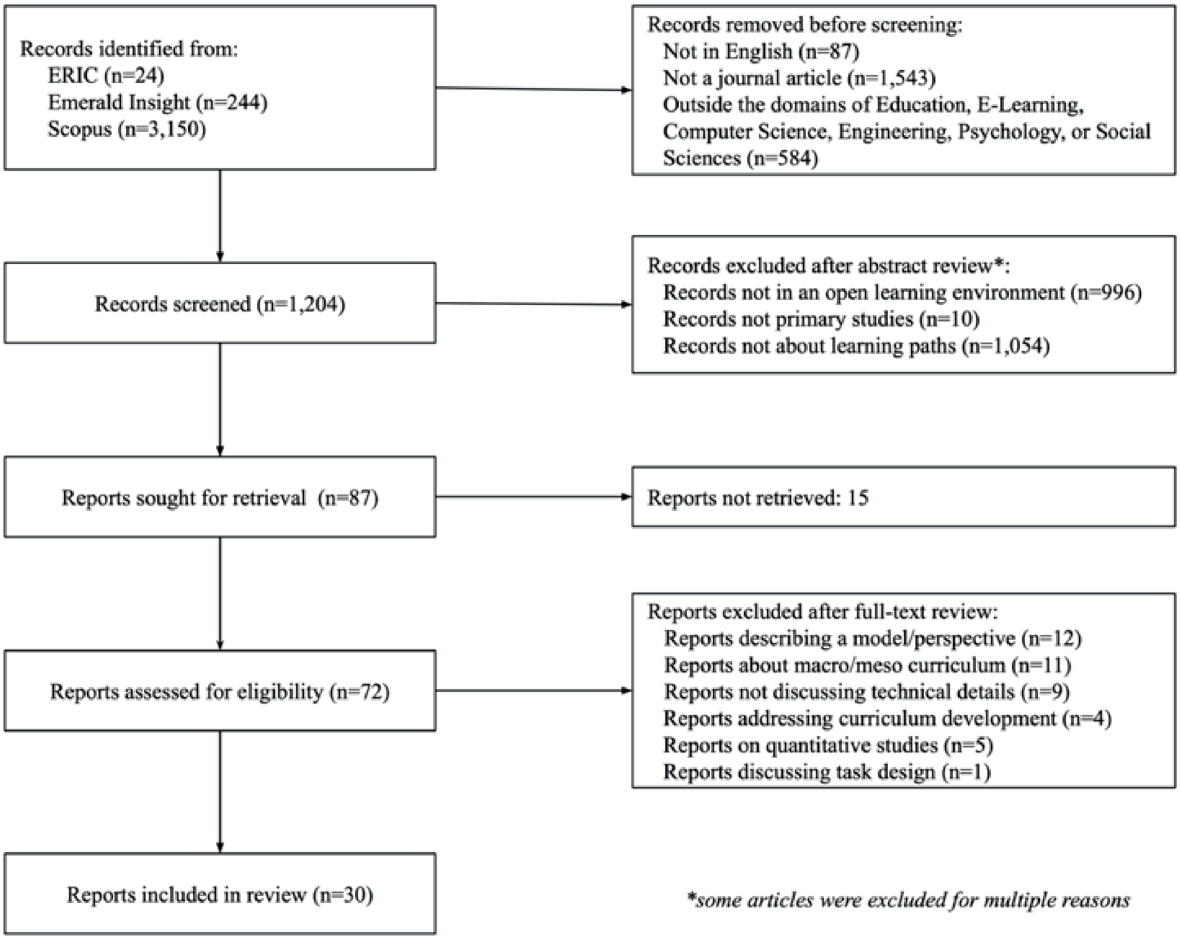

Figure 2. PRISMA flow diagram of the review of nonlinear learning

Data Extraction

All articles that passed the selection phase were extracted in four groups of data:

1. *Course:* This includes the learning platform (e.g., MOOC, classroom setting, simulation study), subject course, department, education level (primary school, secondary school, higher education, professional), course duration, and information about the students (cohort and number of students).
2. *Learning Path Characteristics:* This covers the task sequence approach (hierarchical, procedural, topical, spiral, combination) and curriculum level (nano/individual, micro/classroom). Based on the scope, there are five *curriculum levels*: nano (individual), micro (classroom), meso (educational institution program), macro (national), and supra (international policy) (Leyendecker, 2012). Given the study's focus on learning sequences directly taught to students, we discuss only the nano and micro curriculum levels.
3. *Open Learning Characteristics:* These include the instructional method (e.g., project- or problem-based contexts (Land & Oliver, 2012)), type of open-ended learning (open-ended learning goal, open-ended means, or both (Hannafin et al., 1999)), learning activity, and contexts for projects or problems (i.e., externally imposed (problems that are explicitly specified), externally induced (problem contexts are presented and students generates problems), or individually generated (students generate both the context and problems) (Hannafin et al., 1999).
4. *Personalisation:* This category encompasses the learning technology used, personalisation method, type (i.e., adaptable, adaptive), and enabler role (educator, technology).

Data Analysis

The 30 reviewed studies came from 27 different journals. Most of these studies focused on higher education, as shown in Figure 3. This is likely because colleges and universities have unique needs and pedagogical methods. For example, in subjects like algebra, higher education focuses more on problem-solving and critical writing, while high school often focuses on memorizing methods (Venezia & Jaeger, 2013).

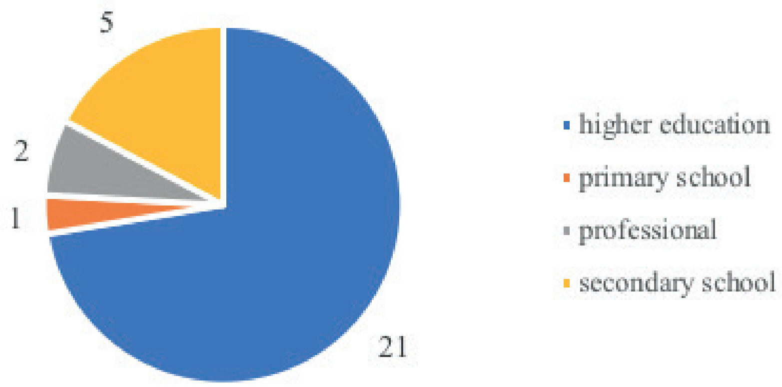

Figure 3. Overview of the educational level of reviewed studies

By comparing the course format, the majority used classroom settings (83,3%, n=25), while only 4 studies use Massive Open Online Courses (MOOCs), and 1 study used simulated environments. Moreover, we found that three-quarters of the studies used a micro-level curriculum, while the remainder used a nano-level curriculum. For example, the educators applied the Geotech Centre's Geospatial Technology Competency Model to enhance the students' geospatial science and analysis skills. In the study, the educators used a micro-level curriculum by providing the environment and activities for learning, e.g., socio-environmental science investigations activities and a map of the sampling area as learning material (Hammond et al., 2018).

All studies, except one which used simulated students, discussed real case studies. There was a variety of subjects, and the medical/pharmacy and engineering subjects in higher education were the two most popular. By categorizing contexts for projects or problems, we found that the reviewed papers are evenly distributed (Table 1).

Table 1. Contexts of problems or projects

Enabling context	Case studies
Externally imposed	A specified problem is assigned, and the students then find solutions to it (Guiter, Sapia, Wright, Hutchins, & Arayssi, 2021; Johnson, Murphy, & Griffiths, 2019; Miller & Sehgal, 2016), choose preferred experiments (Farley, Fringer, & Wainman, 2020; Hietanen & Ruismaki, 2016; M. J. Zhang, Newton, Grove, Pritzker, & Ioannidis, 2020), adjust virtual solutions (Applebaum, Vitale, Gerard, & Linn, 2017), or work on real solutions (Chaudhury, 2021; Flores, 2018; Pepin & Kock, 2021; Verbic, Keerthisinghe, & Chapman, 2017).
Externally induced	An ill-structured problem is presented, then students search for the preferred problem, then propose a solution (Hammond et al., 2018), and work on solutions (Hero & Lindfors, 2019; Hulls & Rennick, 2020; Kowalski, Hoops, & Johnson, 2016; Nikolic, Castronovo, & Leicht, 2021; Rodriguez, Perez, Nunez, Banos, & Carrio, 2019).
Individually generated	Students choose projects according to their preference (Lim, Chua, Yuen, & Hilmy, 2019; Mita & Kawahara, 2017; Van Woezik, Reuzel, & Koksma, 2019), students' needs (Mullen et al., 2017), patients' needs (Pavon, Pinheiro, & Buhr, 2018), students' desired career (Burnham, 2020); students' daily life (Aflatoony, Wakkary, & Neustaedter, 2017) and contemporary sustainability topics (Dharmasasmita, Puntha, & Molthan-Hill, 2017).

FINDINGS

RQ1: How do OLEs Support Nonlinear Learning Path?

Nonlinear learning paths are most effective in open learning environments. Although they are often associated with technology and Massive Open Online Courses (MOOCs), classroom learning can also be nonlinear. This section gives a detailed look at nonlinear learning in both MOOCs and classrooms settings.

Nonlinear in MOOCs

MOOCs, as digital platforms, allow for easy, non-sequential access to content. The four reviewed studies explain how nonlinear learning works as follows:

> *"There are new users, experienced users, and advanced users.… students will take multiple versions of this course over the length of their careers rather than work through all the material as a single course" (Mullen et al., 2017).*
>
> *"Pre-recorded micro-lessons exposed students to key concepts. Students can review confusing concepts and break them into more understandable portions and proceed at their own pace" (Wu, Ma, & Yu, 2021).*
>
> *"… learners do not have to follow the designed sequence of the course activities as they have the autonomy to pursue their own sequence of learning activities, such as when to watch a video lecture, and which course activity … Moreover, learners are free to skip any of the course activities" (Wong, Khalil, Baars, de Koning, & Paas, 2019).*
>
> *"… automatically tell students the most important concepts of the upcoming chapter, which can be helpful …. Based on such guidance, they can have a vision of the course, or check whether they have achieved these concepts before they take an assignment"* (M. Zhang, Zhu, Wang, & Chen, 2019).

One study supports nonlinear learning based on path selection according to user needs and capabilities (Mullen et al., 2017). Therefore, the learning path for new users is different from the one for experienced or advanced users. The other three studies enable nonlinear learning by offering (i) freedom to skip course activities, (ii) opportunities to review confusing concepts, and (iii) content recommendations based on learning performance (Figure 4). As shown in Figure 4, learning might begin with 'A' content, but students can navigate through the material in any order they choose. This flexibility is a key feature of nonlinear learning paths.

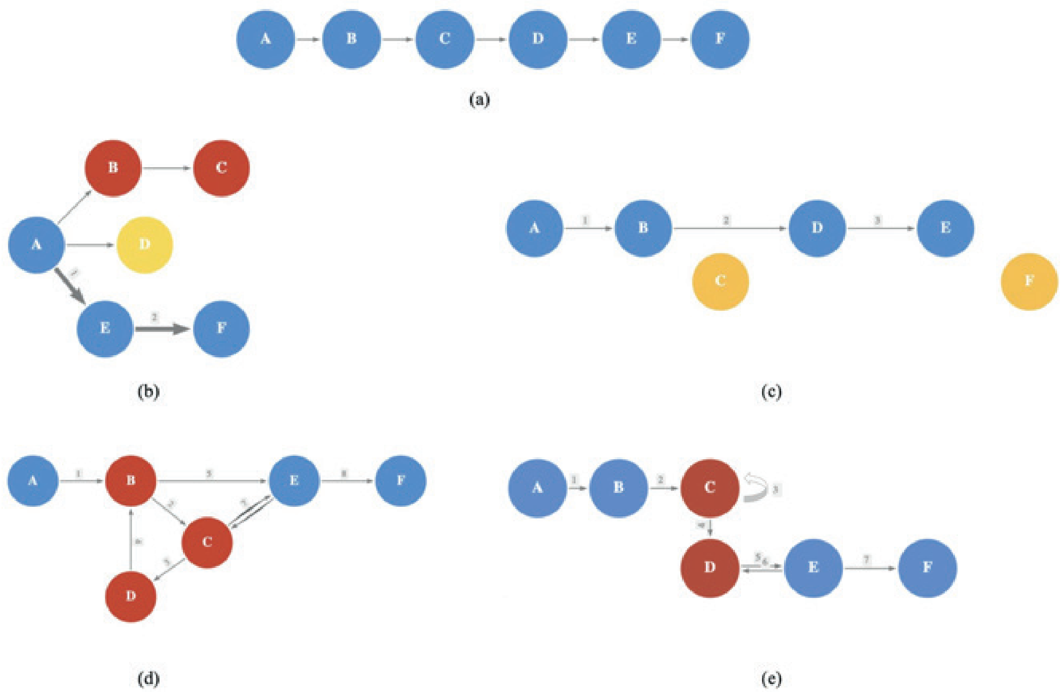

Figure 4. The different learning paths: (a) a linear path, (b) a nonlinear path by selecting 'A-E-F' path, (c) a nonlinear approach by skipping 'C' and 'F', (d) a nonlinear path with a cyclic 'B-C-D' path, and (e) a nonlinear path by re-learning 'C' and 'D'.

Nonlinear Learning in a Technology-Supported Classroom

Open learning environments can be implemented in classrooms through project-based and problem-based learning, as these approaches support individuals in leading their own learning. Therefore, students should recognise what is already known and perform a self-assessment of what needs to be known (Hannafin et al., 1999; Land & Oliver, 2012). Students develop and reconstruct their understanding, for instance, during the artefact creation phase of project-based learning. Such processes imply that "*learning does not occur in linear and discrete steps*" (Krajcik & Blumenfeld, 2006).

Several nonlinear classroom activities are described in the reviewed literature, i.e.:

1. *Face-to-face or online discussions:* Face-to-face and Zoom discussions (Guiter et al., 2021) are synchronous, while written discussion forums on specific websites (e.g., (Chaudhury, 2021; Dharmasasmita et al., 2017)) are asynchronous.

   Discussions, a popular learning activity, can take place within both formal and informal learning groups. Formal groups aim to solve specific problems or complete projects within a given timeframe (Udvari-Solner, 2012). In such groups, discussion is a means of exchanging and understanding ideas from different perspectives. Team meetings and weekly progress reports are examples (Nikolic et al., 2021). Discussion also benefits from a variety of social interactions. Students may interact with educators, project teams, friends, helpdesks, families, specialists, and broader community. Therefore, learning through discussion is not linear but often *iterative* or *cyclical*: it is focused on the common project goal, 'diverging' when working in the group, and 'converging' with the help of the tutor providing focused advice (Pepin & Kock, 2021).

   Discussions in informal learning groups are characterised by (a) the students' seeking answers to what needs to be known, (b) reflection on difficulties to deepen or improve understanding, and (c) feedback from peers or facilitators as a response or guidance (Ellis, Calvo, Levy, & Tan, 2004). The examples include students asking educator in an unstructured discussion form (Van Woezik et al., 2019) or sharing knowledge in groups and classroom-wide discussions (Johnson et al., 2019). Another example is when students can discuss solutions to programming difficulties, which then are modelled by the educator using a computer (Hulls & Rennick, 2020). Discussions in informal learning groups involve perceiving, thinking, and even acting, which are not linear sequences, but rather *circular*, *recurrent* processes (Peters, 2002).

2. *Self-study materials* supplied by the educator. These settings expected students to learn the materials on their own. The self-learning process varied; for instance, there were no teaching or tutoring sessions, but students could ask the educator about the material during weekly sessions without a predefined agenda (Van Woezik et al., 2019). In other research, students were permitted to skip the educator-created content (Hietanen & Ruismaki, 2016), freely access tutorial, and simulation content (e.g., (Applebaum et al., 2017; Nikolic et al., 2021)), and freely view virtual pathology slides (Guiter et al., 2021). Another study used semantic web technology that expose the learning material maps as a network structure (Wu et al., 2021).

3. *Student-created contents,* which students find and learn on their own. Such contents are generally used in experiential learning, problem-based learning, project-based learning, and challenge-based learning. This approach to learning is nonlinear. For instance, a study reported resident doctors overseeing patients who are being discharged. The residents not only monitor the patient in the hospital but also during follow-up visits at home. In this case, the educator does not provide materials; instead, the residents learn through practical experience, such as coaching patients, compiling medication records, and identifying discrepancies in medication (Pavon et al., 2018).

4. *Project mentoring or coaching* for project artefact completion and improvement. This current study adopts a definition where the "*mentor takes on the role of a guide and sage with the characteristics of a helper, teacher, and adviser, while the coach provides individualised professional guidance established with a conversation about methods and performance*" (Carr, Holmes, & Flynn, 2017). As a learning activity, students get mentoring or coaching projects from experienced people, e.g., educators (individuals or teams), teaching assistants (Farley et al., 2020), parents, grandparents, local experts, and distant experts (Flores, 2018).

Mentoring and coaching involves complex engagement and dialogue, more than the Initiate-Response-Evaluation pattern. The student activity goes beyond answering, so a student can expand a response and a teammate can add another answer. Making project artefacts also takes time, as it involves a process of constructing and reconstructing students' understanding. Students also should connect and synthesise ideas. Hence, students have some learner agency (Gardner, 2019). Giving learners autonomy and agency clearly demands a 'paradigm shift' to following more connectivism or nonlinear learning (Bali, el Ahwal, Hashad, Fahmy, & Hussein, 2021).

5. *Peer feedback/interviews/mentoring:* Peer feedback helps to develop abilities, such as critical thinking, listening to and acting on feedback, and sensitively assessing and providing feedback on others' work. A student constructs a more complex understanding by communicating what they know. Hence, peer feedback improves learning because students actively articulate evolving subject matter understandings (Liu & Carless, 2006), which implies nonlinear thinking. There are explicit peer roles found in the reviewed studies, such as:

   > *"Peer-mentoring situations in which one group with a better initial design can advise the other pair on how to increase distance" (Applebaum et al., 2017)*

   > *"…an interview activity which aims to help students find realistic problems by interviewing one another" (Aflatoony et al., 2017)*

   > *"Ability to cooperate allowed the fulfilment of one's own goals within the group work or learning by listening to and observing others" (Hietanen & Ruismaki, 2016)*

   > *"…look out for any constructive feedback from the learner's peers that may have brought resolution to the mistakes…" (Lim et al., 2019)*

6. *Co-learning:* Co-learning describe educator-learner relationships as reciprocal to work and to create shared meaning. The strong collaboration creates an environment where "*people learn through their interaction and participation with one another in fluid relationships*" (Booth, 2014). It also integrates research and teaching where students and educators act as co-learners (Rodriguez et al., 2019). Another term for co-learner is co-experimenter (Pepin & Kock, 2021) and co-developer (Lim et al., 2019).

RQ2: To What Extent do OLEs Enable Personalised Nonlinear Learning Paths?

Nonlinear learning encourages students to choose their own learning path. This proactive behaviour is assumed to be easier for Western culture, which values individualism, personal autonomy, and freedom of choice (Gazi, 2014). However, a transition from directed learning to open-ended learning settings in both East and West requires time and effort. Reluctance is an example of a problem that may occur. For instance, just one-sixth of students enrolled in a course on a campus in the Netherlands opt for self-directed learning, while the remaining students prefer the regular format (Van Woezik et al., 2019). We also found some learning barriers in the reviewed papers, i.e., misunderstanding of project or problem scope, campus policy, educator roles reposition, teamwork issues, technology concerns and students' negative emotions.

Many of the reviewed studies showed learning support from educators; however, they did not specifically address learning path personalisation. The following are the OLE educator scaffolds:

1. *Course design*: educators act as co-learners (Flores, 2018), replicate the process of real-world projects (M. J. Zhang et al., 2020), allow for minor errors (Farley et al., 2020), remind students of targets and deadlines (Flores, 2018; Hero & Lindfors, 2019; Nikolic et al., 2021), monitor student progress on projects (Aflatoony et al., 2017; Nikolic et al., 2021; M. J. Zhang et al., 2020), and provide self-assessment or self-reflection to assess understanding (Wong et al., 2019).
2. *Consultation*: educators assist students with consultation and provide feedback on proposed designs, strategies, processes, and materials (Aflatoony et al., 2017; Farley et al., 2020; Hero & Lindfors, 2019; Kowalski et al., 2016; Nikolic et al., 2021; M. J. Zhang et al., 2020), and discuss alternative suggestions (Hero & Lindfors, 2019; Miller & Sehgal, 2016).

3. *Additional activities* or training (Hero & Lindfors, 2019; Rodriguez et al., 2019).
4. *Technology*: educators facilitate the use of digital pedagogical tools (Dharmasasmita et al., 2017).
5. *Motivation*: educators encourage students to participate in critical thinking (Dharmasasmita et al., 2017; Flores, 2018; Nikolic et al., 2021).

Numerous papers reviewed utilise technology-supported learning (refer to Table 2). Following Hannafin et al.'s classification of OLE tools, we discovered that manipulation tools facilitate nonlinear learning in various ways. Regarding personalisation (Rahayu, Ferdiana, & Kusumawardani, 2022), most of the reviewed manipulation tools still lacked features for recommending learning paths. However, we identified a simulation study used adaptive personalisation to recommend materials based on users' performance (M. Zhang et al., 2019). Meanwhile, adaptable personalisation let students choose their own paths based on their needs and capabilities (Mullen et al., 2017).

Table 2. Use of OLE tools

OLE tool category	Learning technology
Processing tools	Temperature data collection using GPS-enabled iPad (Hammond et al., 2018); open access digital microscopy slides (Guiter et al., 2021); Prezi presentation (Dharmasasmita et al., 2017); Google search engine (Van Woezik et al., 2019); browser to display the learning materials (Mullen et al., 2017; Wong et al., 2019; M. Zhang et al., 2019); linked data-based knowledge navigation system (Wu et al., 2021)
Manipulation tools	Application development environment (Hero & Lindfors, 2019); building information modelling tool (Nikolic et al., 2021); logo designer (Rodriguez et al., 2019); Canva, Piktochart, and Vengage design tool (Chaudhury, 2021); ArcGIS.com suite as geospatial tool (Hammond et al., 2018); Google Sites (Miller & Sehgal, 2016); LEGO NXT/EV3 robot (Hulls & Rennick, 2020); open hardware (Mita & Kawahara, 2017); open-source immersive virtual environment (Lim et al., 2019); Web-based Inquiry Science Environment as virtual model support (Applebaum et al., 2017); learning path recommender system (Mullen et al., 2017; M. Zhang et al., 2019)
Communication tools	Email (Chaudhury, 2021); online quiz (Dharmasasmita et al., 2017); discussion forum (Wong et al., 2019)

DISCUSSIONS

Implications

Nonlinear learning allows students to choose and determine their own learning path. We propose some practical implications to implement it more effectively. *First*, the nonlinear learning path can be a self-choice, but educators can also implement it in the classroom and the MOOCs. Educators can facilitate nonlinear learning in the classroom through discussions and mentoring/coaching projects. In MOOCs, technology can aid with the learning path recommenders.

The recommender system is one of the artificial intelligence technologies that can be used in e-learning. The learning materials are the most frequently recommended items in the e-learning domain, followed by learning paths and feedback (Rahayu et al., 2022). Learning path recommender systems function variedly. Based on the approach, the learning path recommender system might be in the form of *course generation (CG)* or *course sequence* (CS). The CG develops and recommends whole paths to students in one recommendation, and grading occurs upon the pathway completion. In contrast, CS generates and recommends paths to students based on their progress and allows for assessment during learning (Nabizadeh, Leal, Rafsanjani, & Shah, 2020). Thus, the CS approach supports nonlinear learning by allowing students to make choices either at the start or during their learning.

Depending on the number of users, the learning path recommender system can be set up either at individual (*individual sequencing*) or group (*social sequencing*) levels (Rahayu et al., 2023). Individual sequencing provides the optimal path for each student to use during learning, whereas social sequencing suggests an ideal collective path for the entire group. Both strategies allow nonlinear learning, but individual sequencing is better suited for individual students.

Second, as technology advances, the demand for nonlinear learning will grow substantially. Learning materials and project types are related to this need. For example, both blended learning and flipped learning models encourage the use of nonlinear digital materials. Moreover, projects can often transition into digital formats, whether in blended environments or fully online courses.

Third, nonlinear support is beneficial for students, but only for those with strong learner agency. However, nurturing learner agency is time-consuming and challenging. Previous studies have explored various strategies to support this, including methods like ungrading, self-grading, creating content by learners, allowing students to choose their own learning path (Bali et al., 2021), enhancing information literacy skills, focusing more on students' experiences and emotions (O'Brien & Reale, 2021), and meeting psychological needs (Kaplan, Bar-Tov, Glassner, & Back, 2021).

Fourth, the current review indicates that the success of open-ended projects does not depend solely in the hands of students. Developing a project or artefact often encounters challenges along the way. The challenges can be attributable to the lack of hard skills (such as insufficient understanding of the project's scope or technology issues) or lack of soft skills (e.g., writing, teamwork, time management, emotional management). Thus, students need motivational or competence-based external help, such as design, communication, training, and technology support.

Research Agenda

The current study suggests directions for future research on nonlinear learning. *First*, it emphasizes the need for qualitative research to understand how students engage in nonlinear learning. Most existing research focuses on how to enhance course design from the educators' perspective or on curriculum resources and tools (Flores, 2018; Pepin & Kock, 2021). Course plans, student self-reflections, and daily logbooks can be used as source documents.

Second, learner–content interaction often assesses interaction data, such as learner engagement (Powell & Leary, 2021), behavioural effort (Al Mamun, Lawrie, & Wright, 2022), and learning activities (Le et al., 2022). Therefore, there is a need to study the learning path patterns concerning access to materials via the MOOCs platform. Such patterns can be used to improve the learning materials and navigation over time.

Finally, nonlinear learning allows combining the educator-supplied resources with the student internet search. Materials provided by the educators are no longer the only source of information. Students can find supporting information and enriched material as the internet grows (Ismail, Balkhouche, & Harous, 2020). Future studies could pair information sources and follow-up actions to effectively help educators and students.

Limitations

This research represents the first attempt to study the learner-content interaction from the perspective of learning path. The challenge lies in the vast scope of nonlinear learning and the unlimited materials access available to students. The patterns of nonlinear learning interactions may differ across scientific disciplines (like science, engineering, humanities) and cultures, especially in terms of learner agency (Blaschke, Bozkurt, & Cormier, 2021). Along with that, there is no sufficient information from the students' point of view about how they interact with the content. Hence, we could not generalise practical inferences about the personalisation needs. More interesting patterns are expected from further research.

Furthermore, this review includes only English peer-reviewed journal publications. Future research can also include conference papers, including those in other languages.

CONCLUSION

The learning path is critical to learning. Moreover, nonlinear learning paths not only offer greater flexibility but also add complexity compared to linear learning paths. The current study examines how nonlinear learning paths are being adopted in the open learning environments. We reported 30 journal articles using the PRISMA 2020 Statement. Below is a summary of the findings:

1. Nonlinear learning, as a form of student-centred learning, aligns with the natural human ability to think non-linearly. With the expansion of the internet, nonlinear learning involves jumping non-sequentially between different pieces of information using *hyperlinks* -or links- among learning materials.
2. Naturally, nonlinear learning applies effectively *both in the classroom and on the MOOCs platform*. Examples of nonlinear-supported activities in classroom are face-to-face or online discussions, self-study materials, student-created contents, project mentoring or coaching, peer feedback/interviews/mentoring, and co-learning activities. Using MOOC platforms, nonlinear learning allows students to choose from multiple learning paths, engage in cyclical learning path, or skip around between sections.
3. Nonlinear students may find themselves disorients by incoherent learning materials. Personalisation is key to prevent such disorientation. However, the personalisation of nonlinear learning path has not been extensively explored. Technology offers a solution through adaptable or adaptive recommender systems that suggest specific learning paths to students.

Recommendations for Educators

Our research shows that nonlinear learning aligns well with how people naturally think and is practical for educational use. Therefore, we propose two recommendations for educators to help students learn better through nonlinear approaches. *First*, use a variety of nonlinear activities both in classroom settings and online platforms. Supports that have been given in person and in real-time, such as discussions and mentoring, also needs to change through technology. For example, social media can be used to keep students motivated, collaborative technology can help with group work and synchronous communication tools can be used for customer meetings or professional consultation (Cochrane & Antonczak, 2014; Mac Callum, Day, Skelton, Lengyl, & Verhaart, 2015). Moreover, online peer monitoring and peer assessment can be utilised to monitor and evaluate projects (Cochrane & Antonczak, 2013; Gogus, 2012). Educators (Rehman, Elshareif, & Khan, 2023) and other professionals, such as instructional designers, instructional project managers, media specialists, technology coordinators, system administrators, developers or programmers, and evaluators, must collaborate to implement these changes (Huang et al., 2019).

Second, make learning more personal with technology. This includes creating learning materials and projects that support nonlinear learning. Furthermore, educators could also use learning path recommender systems that can automatically adjust learning paths based on a student's performance and preferences. This approach can provide a more personalised and effective learning experience, helping to prevent disorientation.

Authors' Note: This work was funded by RTA Program Universitas Gadjah Mada with Grant Number 5075/UN1.P.II/Dit-Lit/PT.01.01/2023.

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