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A scoping literature review of learning progressions of engineering education at primary and secondary school level

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ABSTRACT

Background: This scoping literature review was undertaken by the Science and Engineering Education Research and Innovation Hub at The University of Manchester to enhance the understanding of how teachers can be supported to plan for progression in engineering education in primary and secondary schools in England.

Purpose & Method: The aim of this literature review is to provide insight into Learning Progressions (LPs) published globally for primary and secondary school level. In setting out the context and parameters for the study the paper identifies and compares definitions for LPs. It synthesises emergent themes from 25 academic papers.

Findings: Four main findings were deducted from the data papers. Firstly, UK curricular were not discussed. Secondly, within the dataset near parity between science and engineering-focused papers was revealed. Thirdly, of the data papers reviewed nearly the same number used pre-existing definitions of LPs to those that did not offer any definition or description of LP. Furthermore, around half this number created their own, or used a generalised description of LPs. Finally, the data papers highlighted a lack of common definition for engineering education LPs, unlike science LPs. None of the data papers provided an LP specific to engineering education aligned to the National Curriculum (NC) in England.

Conclusions: Four recommendations emerge: i) engineering education should be recognised as a distinct subject within the NC for England; ii) more academic research and curriculum development is required within the field of engineering education LP specifically aligned with the NC in England; iii) industry and education would benefit from further collaboration to ensure that their respective needs and positions are adequately met through schools; iv) teacher professional development and resources need focused auditing and investment.

KEYWORDS
Engineering learning progression; primary school; secondary school; engineering curriculum

Introduction

There have been drives to raise the status of engineering within mainstream primary and secondary (4–14 years) school curricula by including the subject more explicitly within the

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teaching of science or technology or by developing integrated STEM (science, technology, engineering, mathematics) education programmes that position engineering as the context to which content knowledge in the other three subjects is applied. These developments can be seen in countries in North America, Western Europe and Asia (Vries, Gumaelius, and Skogh 2016; Hynes et al. 2017). In parallel, there has been an increased interest in developing Learning Progressions (LPs) to aid the planning and evaluation of teaching and learning in engineering education.

In England, Engineering is not currently a specifically designated NC subject at either primary and lower secondary schools level. However, skills and practices of engineering, for example, making objects including mechanisms such as levers etc. are referenced within the NC for Design and Technology (D&T) in England, and could be argued to be engineering. Teachers in English mainstream schools are required to ensure that pupils should learn and apply D&T skills and knowledge in a variety of contexts, including engineering ('National Curriculum in England: Design and Technology Programmes of Study' n.d.). In other countries of the United Kingdom, engineering has recently been included in the Education Scotland, Technologies, Experiences and Outcomes and in the Welsh Curriculum revisions ('Science and Technology: Statements of What Matters – Hwb' n.d.; 'Experiences and Outcomes | Education Scotland – Technologies' n.d.)

However, engineering enrichment experiences in England can be found on an ad hoc basis in schools where there is a specific driving ethos or teacher designing such offers for pupils. Some schools are pioneering the integration of Engineering Habits of Mind within NC subjects (Lucas, Hanson, and Claxton; Lucas et al. 2017).

This scoping literature review was stimulated to support the Tinkering for Learning curriculum development programme, such that an enhanced understanding of how teachers can be supported to plan for progression in engineering education is developed ('SEERIH Innovations' n.d.; Bianchi and Chippindall 2018). As well as academic literature, the authors of this study draw on their experience in curriculum and professional development in the field of science education. The study of school-level LPs is found to be developed in the science and mathematics but less so in technology and engineering. This results in better understanding of how to develop conceptual understanding in science and mathematics (Alonzo 2012; Corcoran, Mosher, and Rogat 2009). The paper builds on and furthers understanding of engineering education within school settings. It seeks to identify whether, beyond England, educators have access to frameworks and/or exemplification of progression for children of 5–14 years of age in order to guide the teaching and learning process. Undertaking a study of this type is significant at a time when the UK devolved nations of Wales and Scotland have given explicit recognition to engineering within their revised National Curricula; however, no such move has yet been leveraged in England. This paper therefore supports future policy and curriculum development where purpose is to explicitly address engineering within the English 5–14 years education system for STEM.

The aim of this literature review was to provide an overview of LPs published globally for primary and secondary school level. It is noted that the term 'pre-college' is often used to define primary and secondary school age ranges. Setting out the context and parameters for the study, the paper identifies and compares definitions for LPs and how these were devised. It synthesises emergent themes from 25 academic papers.

Engineering education within the education pipeline

There is desire for education systems around the world to produce not just more engineers in traditional fields, such as construction and water engineering, but for these to be developed in new fields of research such as clean energy, artificial intelligence and robotics ('About the Queen Elizabeth Prize for Engineering' n.d.) ('Grand Challenges – 14 Grand Challenges for Engineering' n.d.). In response, some countries have integrated engineering practices and knowledge into their school curricula. The NC in England is yet to include engineering explicitly in the primary and lower secondary level, but new research and development to exemplify how Engineering Habits of Mind can be embedded in the teaching of NC subjects is emerging (Lucas, Hanson, and Claxton ; Lucas et al. 2017). In contrast, young people move through the education system into Higher Education where the range of engineering disciplines is highly specialised and degree options require understanding of the nuances between fields such as mechanical, aerospace, civil, chemical, biochemical engineering etc. The assumption that the generic term of 'engineering' poses an additional challenge and potentially obstacles for young people who are seeking to pursue a career in an engineering discipline.

Raising awareness of engineering to primary and secondary school pupils has been long invested in due to industrial, economic and social concerns experienced in the UK. ('OECD Future of Education and Skills 2030 – Organisation for Economic Co-Operation and Development' n.d.). Industry continues to report the impact of low participation rates of students, in particular girls, in advanced level science and mathematics qualifications, resulting in ongoing shortfalls of qualified engineers entering the workforce ('Educating for the Modern World' 2018).

Little has changed in England over the past decade as noted in the Royal Academy of Engineering 'Engineering Skills for the future The 2013 Perkins Review Revisited Report', which states that:

> . . . while there has been progress and reform in certain areas, in particular in improvements to careers education in schools . . . this review has brought into sharp relief the many issues that continue to impact engineering skills in the UK.(Royal Academy of Engineering (Great Britain) and Education for Engineering (Great Britain) 2019, 55)

Different models that integrate engineering formally or informally do exist in other countries, e.g. in the USA, engineering is one aspect within an integrated STEM programme, used to link science and mathematics (Chabalengula and Mumba 2017; Colucci-Gray et al. 2017). In the Korean NC, STEM has been extended to STEAM by including Arts. In this way, greater emphasis is given to creative thinking as an aligned aspect of engineering education (Jho, Hong, and Song 2016).

In Australia, engineering is included within 'Technologies' curricula (Vries, Gumaelius, and Skogh 2016, 101–120). In England, apart from reference to it as context for D&T, engineering can occasionally be found as the core focus of the curriculum, e.g. in specialised University Technical Colleges (Dominguez-Reig and Robinson 2018).

Learning progression (LP)

Learning Progressions are statements that focus on what pupils learn in a progressive and incremental way, with increasing sophistication in their knowledge of topics within a subject area. LPs provide a framework that offers the opportunity for teaching and learning objectives, objectives that are designed to provide teachers with common goals against which to plan for progression in learning over time. They also support formative and summative feedback and assessment practice (Kobrin et al. 2015; Shea and Duncan 2013; Shepard 2018). As engineering is a process of iteration, it is appropriate that engineering education might also take an iterative, rather than a liner, approach to supporting learning.

As the inclusion of engineering within STEM programmes increases, teachers report that a lack of standardized or formative assessment practices challenge their ability and confidence to teach sequences of developmental STEM lessons (Margot and Kettler 2019; Hynes et al. 2017).

This led to a growing interest, albeit slow, in developing LPs for engineering education in school settings. One of the purposes of this study was to find out how LP's are defined across engineering and STEM globally and see how this related to engineering LPs in England.

The authors focused on two research questions in this study:

(i) What evidence is there of the use of LPs in engineering education and associated STEM subjects, for primary and secondary pupils across the world?
(ii) How are LPs described within the context of supporting the engineering education teaching and learning in English primary and secondary schools?

Methods

Scoping review

A scoping review was undertaken because, according to Armstrong et al. (2011), descriptions that explain a scoping review are processes of mapping the existing literature or evidence in order to explore the extent of the literature in a research field before undertaking a systematic review. Unlike a systematic review, a scoping review does not demand detailed data extraction or quantitative data analysis, nor the application of quality criteria to the research methods used in the studies reviewed. The synthesis in a scoping review is normally qualitative (Armstrong et al. 2011), arising from the needs of social scientists who required more flexible and iterative review processes. These are useful for mapping existing knowledge and exposing gaps in the current state of knowledge (Thomas et al. 2017).

The framework for scoping reviews devised by (Arksey and O'Malley 2005) was used to guide this review. Having identified two research questions the authors went through the steps of searching for and identifying relevant studies, selecting the studies for inclusion, charting the data, collating and reporting the results.

Search strategy

A range of strategies can be utilised to identify relevant sources in a scoping review but the search can be tailored to the resources available (Armstrong et al. 2011). In this study, the search was limited initially to locating peer-reviewed academic papers, written in English language, using EBSCOhost. This included the databases Academic Search Complete, British Education Index (BEI) and Education Resources Information Centre (ERIC).

Three search terms were used (ref. Table 1) including primary terms for LPs and their possible synonyms were combined using the operator 'AND' with secondary terms 'engineering' OR 'STEM' OR technology. A third set of terms covering the phases of education for ages 4–14 years refined the search further. 'Technology' was included as a separate search term in the subsequent lists, as it can be found as an alternative expression for 'engineering' within some education systems.

The search was limited to peer-reviewed papers as well as a sample of professional texts including book chapters, published in the English language between the dates of January 2009 to August 2018. 2009 was selected as the earliest date because it was the year in which the National Academy of Engineering published its report into the state of engineering education in schools in the USA (Hynes et al. 2017). This report signalled the expansion of interventions to raise the profile of engineering education in schools and gave rise to a significant body of research literature. It relates to the US education system although the theoretical aspects of designing and implementing progression frameworks, where they existed, were purposeful for this study. The end date in 2018 marked the beginning of our research study for which the review findings were needed.

Results yielded over 800 papers that were selected for further investigation by identifying those with titles and abstracts that met the following criteria:

- They referred to the concept of learning progression, either directly or with reference to other approaches to codifying learning, e.g. as assessment rubrics, standards or curriculum mapping.
- They focused on engineering education or engineering in integrated STEM programmes at pre-college level.

Papers referring to Information Technology, Information and Communication Technology (ICT) or Learning Technology were rejected.

Table 1. Search terms for the study.

Key search terms		
Terms related to literature about Learning Progressions	Terms related to literature about STEM or engineering	Terms related to the curriculum level to which the other two are applied
Learning progression*	Engineering	Primary
Progression framework*	STEM (Science, Technology, Engineering and Mathematics)	Elementary
Learning trajectory*		Secondary
Curriculum mapping	Technology	High school

Due to relatively few engineering or integrative STEM progression frameworks identified, the criteria were expanded to include a sample of recent papers about learning progressions in science that enabled a synthesis of ideas about LPs from the science progression research base to inform the review.

Additional literature was also sought by looking at the reference list from selected data papers, and by using Google Scholar to search for citations from identified LPs. resulted in some additional published conference papers on engineering progressions. Two edited scholarly works were also reviewed (Vries, Gumaelius, and Skogh 2016; English and Moore 2018) as they are seminal collections of examples of pre-college engineering.

25 papers were selected through the initial and secondary searches. In the secondary search, the researchers sought papers that fitted into the criteria in Table 2 (below) in at least one or more categories or with the aims of the research.

Coding and analysis

An alphabetised table of the final 25 data papers identifies each paper in terms of:

- title of the paper
- summary of main features
- subject focus
- research methodology used (highlighting papers involving real world research with industry professionals or teachers/students;
- definition of LP used (those that had defined or described LPs; those which had created their own or given examples of LPs.)
- LP examples
- emerging issues in light of our research aims.

Table 2. Representation of ranking criteria.

Point score	1	2	3
The Subject Focus	Science, Technology and/or Mathematics	Engineering and Science, Technology and/or Mathematics	Engineering
Participants and location of the research	Research undertaken by academics only (no inclusion of in service teachers)	Research/LP trialled in a classroom	Research undertaken in tandem WITH practicing teachers
LP definition	No specific reference to or description of LP	General description of LP used	A specific definition of an LP defined and cited
LP examples	No LP offered	An example of an existing LP offered	A new LP offered
Age Range/ Education setting	Secondary/College (11–18 years)	Pre K to secondary (and variants within that 2–16 years)	Pre-K – Primary only (2–11 years)
Maximum paper scoring	0–5 Low alignment	6–10 Moderate alignment	11–15 High alignment

Table 3. Ranking outcomes related to data papers.

Alignment Ranking	Score ranking	Number of data papers in this category
High alignment	11–15	11
Medium alignment	6–10	14
Low alignment	0–5	0

Themes were identified across the paper set synthesising emergent patterns and ranking against specific criteria (ref. Table 2). This identified papers with high, medium or low alignment to the research aims (Whittemore and Knafl 2005).

Limitations

The literature on engineering in primary and secondary education is diverse. Together with the fact that the research is in its infancy, the data set arrived at in this study is limited to the fields of exploration and the year span explored. Furthermore, since the purpose of scoping the literature was to highlight emerging issues and knowledge gaps so as to inform the design of an experimental LP in engineering education for primary and secondary curriculum in England, it is possible that the selection of papers from the initial 800 papers will have been influenced by unintended bias.

Results

The results are organised into three main formats: a table of results outlining scoring; a list of papers with comparative details including a score and outlining the literature, and descriptive findings incorporating diagrams to explain themes emerging from across the sources in relation to the research questions.

The data consist of 25 papers which will collectively be henceforth referred to as the 'data papers', as distinct from any papers that were used to establish context of justification for methodology. The overall score for each paper was determined using Table 2. Of the 25 data papers the total leads to a ranking as follows:

High-alignment ranked data papers in alphabetical order

Table 4. High-alignment ranked data papers in alphabetical order

Finding 1 (Table 5): None of the data papers referenced LPs relating to engineering education in England

All the data papers discuss LPs related to curricular outside of the four countries of the UK. Only one European country, namely Germany, was referenced in the data papers.

Finding 2 Data papers related relatively equally to science and engineering curricula

The breakdown of the subject areas of the data papers shows near parity between science (44%) and engineering (44%) papers within our dataset. Only two papers related to technology or mathematics curricula, 4%, respectively. *Finding 3* (ref Figure 1)*: Definitions of LPs within the data papers were inconsistent.*

40% of data papers used pre-existing definitions of LPs, compared with 36% that did not offer any definition or description of LP. 24% used their own, or a generalised

Table 4. High-alignment ranked data papers in alphabetical order.

No.	Author	Title and Journal	Score	Main Features	Subject	LP definition referenced	Emerging issues
1	Compton, V. and Harwood, C. (2005)	Progression in Technology Education in New Zealand: Components of Practice as a Way Forward. *International Journal of Technology and Design Education*, 15, 253–287	11	New Zealand, early primary-secondary technology education.	Technology	'Progression in Technology education may be broadly described in terms of the increasing scope of sophisticated ideas, skills and understandings that contribute to a student's technology decisions and activities (Ministry of Education 1995, p25).' (Compton and Harwood 2005, 275)	Contradictory guidance in assessment and progression in technology education. 'Has often been contradictory and not in keeping with theoretical and philosophical underpinnings of *technology* in the New Zealand curriculum.' P284
2	Covitt, B. A., Gunckel, K.L., Caplan, B. and Syswerda, S. (2018)	Teachers' use of learning progression-based formative assessment on the topic of 'Water instruction'., Applied Measurement in Education, 31:2, 128–142,	11	USA Middle to high school	Science – environmental literacy, this example covers the water systems learning progression (WSLP)	No direct definition of LP but implicit definition is given in this statement "Because they provide empirically grounded descriptions of student ideas and trajectories for how those ideas may change over time (National Research Council, 2007), LPs have the potential to support teacher formative assessment practices of setting learning goals, interpreting student ideas, and responding with instruction that helps students develop more sophisticated ideas." (Covitt et al. 2018, 128)	Even with an LP, science teachers tend towards didactic formative assessment, focusing on facts, giving correct vocab or information to students, rather than giving responses that challenge students. Teachers need support to use LPs in formative assessment in ways that help student's master model-based reasoning.
3	Cunningham, Lachapelle, and Davis (2018)	Engineering concepts, practices, and trajectories for early childhood education. In English, L. and Moore, T. eds. Early engineering learning. Singapore: Springer, pp.135–174.	12	Book chapter, Pre-school, kindergarten and primary Singapore	Engineering	Refers to LPs as trajectories, but gives no definition n the text, but see http://eie.org/overview/engineering-trajectories	Although this does not include reference to the testing or evaluation of these trajectories, EiE is one of the pre-eminent examples of engineering school curricula.

(*Continued*)

Table 4. (Continued).

No.	Author	Title and Journal	Score	Main Features	Subject	LP definition referenced	Emerging issues
4	Fonger, N.L., Ana Stephens, Maria Blanton, Isil Isler, Eric Knuth and Angela Murphy Gardiner (2018)	Developing a Learning Progression for Curriculum, Instruction, and Student Learning: An Example from Mathematics Education. *Cognition and Instruction*, 36(1), 30–55	13	This paper explored how learning progressions could be used within maths education to further develop 'a linked understanding of students learning over time through careful articulation of a curricular framework and progression, instructional sequences, assessments, and levels of sophistication in student learning . . . ' (ABSTRACT) Grades 3–5 U.S.A and Canada focused. Authors from a variety of international institutions.	Maths	Direct quotation: 'We take a learning progression to be:(a) a curricular framework and progression of learning goals across big ideas and thinking practices;(b)an instructional sequence;(c)assessments; and(d)levels of sophistication in children's thinking' (cf. Fonger et al. 2018) (P35)	They see is as essential that research into LP be available in practical form for teachers (P 50)

(*Continued*)

Table 4. (Continued).

No.	Author	Title and Journal	Score	Main Features	Subject	LP definition referenced	Emerging issues
5	Grubbs, Strimel, and Huffman (2018)	Engineering education: a clear content base for standards. *Technology and Engineering Teacher*, April, 32–38	12	This research updates the school discipline of Technology and Engineering Education (TEE) through creating curricular frameworks that are working documents to be discussed with the authors' professional community. U.S.A	Engineering	'As Popham (2011) states learning progressions "provide the blueprint for the process – the structure for evidence gathering and adjustment occasions – and serve as a measure of assurance that the evidence-informed adjustments will improve student learning." ('Engineering-Education-A-Clear-Content-Base-for-Standards.Pdf' n.d., 9) (P9) or 'A learning progression can be defined as, "the purposeful sequencing of teaching and learning expectations across multiple developmental stages, ages, or grade levels' ('Engineering-Education-A-Clear-Content-Base-for-Standards.Pdf' n.d., 35)	'The lack of specificity and agreement on engineering learning progressions has contributed toward the unevenness and inconsistency of engineering in P-12 curriculum (NAE & NRC, 2009)' (p9)

(*Continued*)

Table 4. (Continued).

No.	Author	Title and Journal	Score	Main Features	Subject	LP definition referenced	Emerging issues
6	Herrman-Abell, and DeBoer (2018)	Investigating a learning progression for energy ideas from upper elementary through high school. *Journal of Research in Science Teaching, 55*(1), pp.68–93	11	A quantitative study using multiple choice questions 'to over 20,000 in grades 4 through 12 from across the US to text 'a hypothesized learning progression for the concept of energy' (abstract) U.S.A	Science	'The NRC, in *A Framework for K-12 Science Education*, summarizes the role of learning progressions in science education as follows: To develop a thorough understanding of scientific of the world, students need sustained opportunities to work with and develop the underlying ideas and to appreciate those ideas' interconnections over a period of years rather than weeks or months. This sense of developments has been conceptualized in the idea of learning progressions. If mastery of a core idea in a science discipline is the ultimate educational destination, then well-designed learning progression provide a map of the routes that can be taken to reach that destination (NRC, 2012, P.26)' (Herrmann-Abell and DeBoer 2018, 69)	An analysis of the current state of students' understanding with respect to the knowledge identified in the learning progression showed that elementary level students perform well in comparison to expectations but that middle and high school students' performance does not meet expectations.(Herrmann-Abell and DeBoer 2018, Abstract)
7	Moore, Guzey, and Holly (2014)	A framework for quality K-12 engineering education: research and development. *Journal of Pre-College Engineering Education Research*, 4(1), Article 2	12	The purpose of the current work has been the development of a framework for describing what constitutes a quality K-12 engineering education. (abstract) U.S.A	Engineering	Not stated	n/a

(*Continued*)

Table 4. (Continued).

No.	Author	Title and Journal	Score	Main Features	Subject	LP definition referenced	Emerging issues
8	Moore et al., (2015)	An assessment tool to evaluate student learning of engineering. 122nd ASEE Annual Conference, June 14–17, Seattle, WA. Paper ID #12,589	12	Conference paper; K-12 schools. This part of the project focuses on middle school 6th-8 grade, but elementary testing went through the same steps of development USA	Engineering	'According to Olds et al. (2005) assessment is "the act of collecting data or evidence that can be used to answer classroom, curricular, or research questions" (p. 13). Whereas, the Olds et al., (2005) define evaluation as "the interpretations that are made of the evidence collected about a given question" (p.13). The differentiation between these terms is essential to accurately determine the role of each in the educational process, and delineate the next steps for their continued advancement.' (Moore, et al., 2015, P26.117.4) (Describes assessment rather than LP).	Re the purpose of LPs, this provides a useful comparison/contrast between one type of assessment tool being developed for assessing engineering against national standards, and the development of LPs in science, many of which are being developed to support formative assessment.
9	Pinnell, M., Rowly, J., Preiss, S., Franco, S., Blust, R., and, R. (2013)	Bridging the Gap Between Engineering Design and PK-12 Curriculum Development Through the use the STEM Education Quality Framework. *Journal of STEM Education*, 14(4), 28–35.	11	This partnership resulted in the development of the STEM Education Quality Framework (SQF), a tool to guide educators in teaching, learning and refining STEM education. (abstract) USA	Engineering	No LP defined	n/a

(*Continued*)

Table 4. (Continued).

No.	Author	Title and Journal	Score	Main Features	Subject	LP definition referenced	Emerging issues
10	Strimel, G.J., Huffman, T.F., Grubbs, M. G. and Bartholomew, S. (2018)	Establishing progressions of learning in engineering for high school students. 36th International Pupils' Attitudes Towards Technology Conference, Athlone Institute of Technology, Co. Westmeath, Ireland, 18th – 21st June, pp394- for 13pp	12	Conference paper USA High school	Engineering, specifically secondary Technology and Engineering education (TEE) programmes.	'Progressions of learning are defined as a sequenced set of subskills or bodies of enabling knowledge that students must master to achieve a curriculum target (Popham, 2008)' And 'progressions of learning in engineering can serve as a "form of curriculum research that advances a linked understanding of students learning over time through careful articulation of a curricular framework and progression, instructional sequence, assessments, and levels of sophistication in student learning" (Fonger et al. 2018, 30).' ('Seery – Athlone Institute of Technology, Co. Westmeath, Ir.Pdf' n.d., 395)	They distinguish between progression of learning instead of learning progression, as they understand that their work will provide 'a progression of learning' and not 'the learning progression'. Does this mean that sometimes LPs are seen as definitive statements of outcomes?

(*Continued*)

Table 4. (Continued).

No.	Author	Title and Journal	Score	Main Features	Subject	LP definition referenced	Emerging issues
11	Wang, Hsiao-Chi, and Cheng (2015)	Building a learning progression for scientific imagination: A measurement approach. *Thinking Skills and Creativity*, 17, 1–14.	11	This study aimed to build a learning progression (LP) for the development of scientific imagination based on a measurement approach using the BEAR Assessment System (BAS) inanattemptto betterunderstand thecoreideasand thedevelopmental pathofthescientific imagination process as well as align curriculum, instruction, and assessment through LP. (abstract) Taiwan.	Science	Authors cite: 'LPs are successively more sophisticated ways of thinking about a topic or big ideas over an extended period of time and can be used as templates for the development of curriculum and assessments (Smith, Wiser, Anderson, & Krajcik, 2006; Wilson, 2009). LPs have also been described as a conjectural model of learning over time that still requires empirical validation (Duncan, 2009).' and 'Therefore, the purpose of this study was to build a LP for scientific imagination based on the perspective of scientific invention in the informal activities of science education and attempt to understand the core ideas and learning paths of the scientific imagination process for primary school students through feedback from the LPs'. (Wang, Hsiao-Chi, and Cheng 2015, 2)	LP of scientific imagination as a tool for indicators (p4) (very short LP)

Table 5. Breakdown of country of authorship for data papers.

Country	Number of papers
U.S.A	18
U.S.A/Canada	1
U.S.A/Germany	1
Australia	1
New Zealand	1
Singapore	1
Taiwan	1

description of LPs. This illustrates the gap, such that there is no common definition for engineering education LPs, unlike science.

Figure 1 illustrates that science-focused papers more frequently used either an existing definition of LP drawn from earlier literature, or provided their own. In contrast, the engineering-focused papers defined or offered their own definition of LPs.

Figure 2 Breakdown of science and engineering-focused data papers citing or defining definitions of LPs.

Finding 4 (ref. Table 5)*: An LP linked to the NC for England did not emerge within the data papers.*

None of the data papers provided an LP for engineering education aligned to the NC for England, due to the fact that they were written in relation to their own country-specific

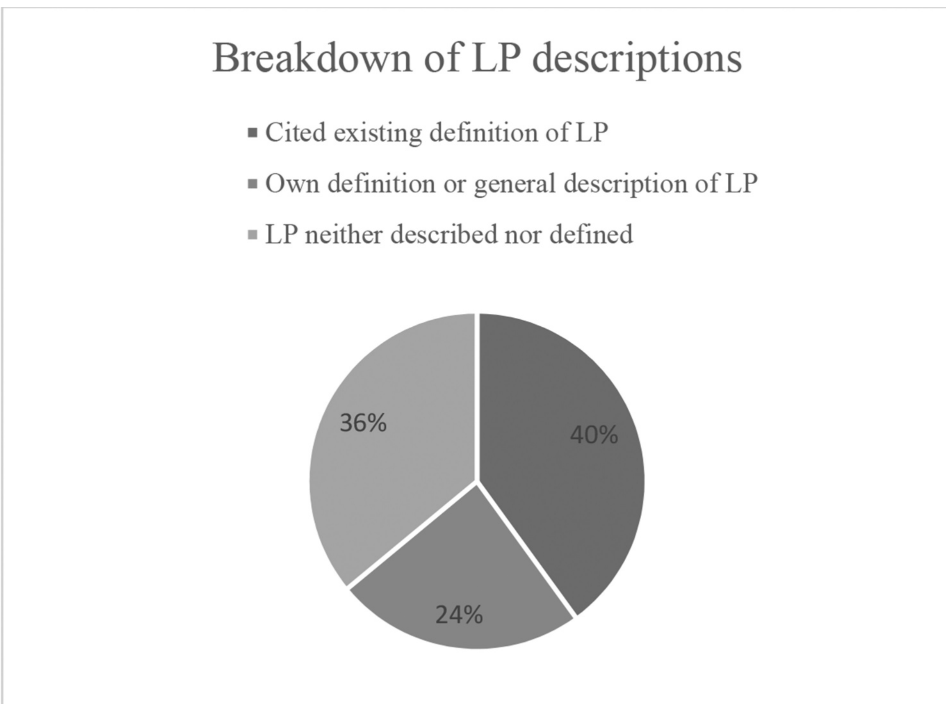

Figure 1. Breakdown of data papers by subject areas.

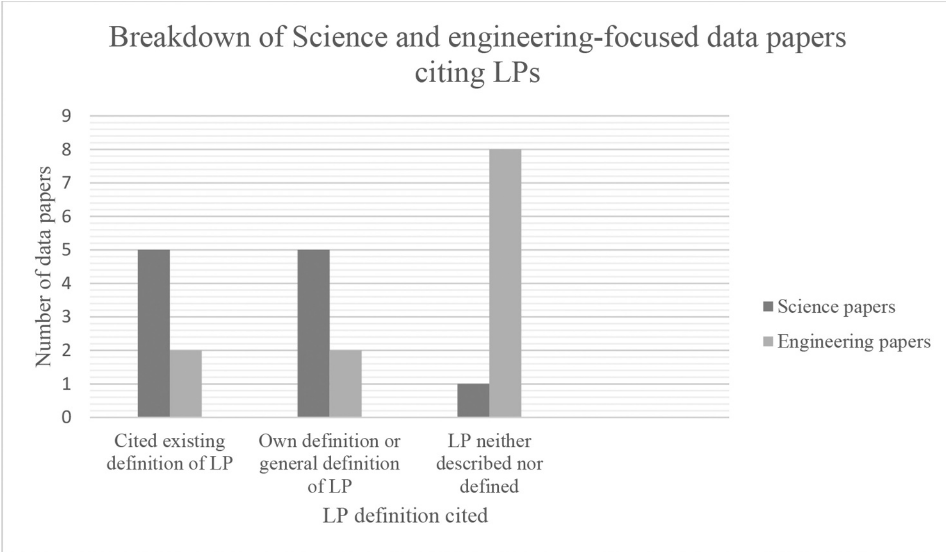

Figure 2. Breakdown of science and engineering-focused data papers citing or defining definitions of LPs.

education system. Table 4 outlines the LP definitions in the data papers and the subject focus of the paper.

Seven definitions were cited, drawn from existing literature, with the National Research Council (2007) being the most cited definition.

Definitions of LP from existing literature cited in the data paper

Data Paper: Alonzo (2012)

Subject Focus: Science

Definition of LP from existing literature cited in the data paper: 'In science, learning progressions have been defined as "descriptions of the successively more sophisticated ways of thinking about a topic that can follow one another as children learn (National Research Council [NRC], 2007, p. 219)".'

Data Paper: Bernholt, S. and Sevian, H. (2018)

Subject Focus: Science

Definition of LP from existing literature cited in the data paper: 'Learning progressions in science are empirically-grounded and testable hypotheses about how students' understanding of, and ability to use, core scientific concepts and explanations and related scientific practices grow and become more sophisticated over time, with appropriate instruction' (Corcoran, Mosher, and Rogat 2009, p. 15; cf. National Research Council, 2007). It holds the promise to 'help us make informed conjectures regarding the most productive directions for science standards, curriculum, and assessment (Duncan and Rivet, 2013, 397)'

Data Paper: Hammer and Sikorski (2015)

Subject Focus: Science

Definition of LP from existing literature cited in the data paper: LPs are defined as 'descriptions of the successively more sophisticated ways of thinking about a topic that can follow one another as children learn about and investigate a topic over a broad span of time (NRC, 2007, p. 214)' (Hammer and Sikorski 2015, 424)

Data Paper: Herrman-Abell, C.F. and DeBoer, G.E. (2018)

Subject Focus: Science

Definition of LP from existing literature cited in the data paper: 'The NRC, in A Framework for K-12 Science Education, summarizes the role of learning progressions in science education as follows: If mastery of a core idea in a science discipline is the ultimate educational destination, then well-designed learning progression provide a map of the routes that can be taken to reach that destination (NRC, 2012, P.26)' (Herrmann-Abell and DeBoer 2018, 69)

Data Paper: Duschl, Maeng, and Sezen (2011)

Subject Focus: Science and mathematics

Definition of LP from existing literature cited in the data paper: 'the learning goal, the learning activities, and the thinking and learning which students might engage' (Duschl, Maeng, and Sezen 2011, 133)

Data Paper: Furtak, E.M., Circi, R. and Heredia, S.C. (2018)

Subject Focus: Science and Biology

Definition of LP from existing literature cited in the data paper: 'As representations of how student understanding develops in a given domain, they also may serve as centre pieces for teachers' ongoing engagement in the processes of alignment between curriculum, instruction, and assessment (Bennett, 2011)' (Furtak, Circi, and Heredia 2018, 143)

Data Paper: Grubbs, Strimel, and Huffman (2018)

Subject Focus: Engineering

Definition of LP from existing literature cited in the data paper: 'As Popham (2011) states learning progressions, "provide the blueprint for the process – the structure for evidence gathering and adjustment occasions – and serve as a measure of assurance that the evidence-informed adjustments will improve student learning."' (Grubbs, Strimel, and Huffman 2018, 35) or 'A learning progression can be defined as, "the purposeful sequencing of teaching and learning expectations across multiple developmental stages, ages, or grade levels" (Hidden Curriculum, 2014, para. 1)' (Grubbs, Strimel, and Huffman 2018, 36)

Data Paper: Strimell, G.J., Huffman, T.F., Grubbs, M.G. and Bartholomew, S. (2018)

Subject Focus: Engineering

Definition of LP from existing literature cited in the data paper: 'Progressions of learning are defined as a sequenced set of subskills or bodies of enabling knowledge that students must master to achieve a curriculum target (Popham 2008)' (Grubbs, Strimel, and Huffman 2018, 395). The authors also quote Fonger et al. 'progressions of learning in engineering can serve as a "form of curriculum research that advances a linked understanding of students learning over time through careful articulation of a curricular framework and progression, instructional sequence, assessments, and levels of sophistication in student learning" (Fonger, et al, 2018, p. 30).' (Grubbs, Strimel, and Huffman 2018, 395)

Discussion

The findings suggest that engineering education LP definitions and examples are limited within the data papers, potentially constraining opportunities for teachers or researchers to take forward ideas and thinking for adaptation, modification and/or development. Science-focused data papers show an increased prevalence of these features.

The discussion is structured against the study's research questions:

(1) What evidence is there of the use of LPs in engineering education and associated STEM subjects, for 4–14 year olds across the world?

The subject areas breakdown of the data papers shows near parity between the representation of science and engineering-focused papers emerging from the scoping literature review. This could denote that progress is being made in each subject; however, closer inspection of the data papers suggests otherwise. A key challenge in understanding the full extent of developments in pre-college engineering education is the range of terms in this area, in particular those used to describe LPs and school age-phases. Engineering as a subject, in mainstream school curricula, has traditionally been associated with named vocational qualifications for 14 year old+ pupils. More recently, the acronym STEM has popularised the integration of science, technology, engineering and mathematics programmes.

In many integrated STEM programmes, engineering is used as the integrative element, either through the use of the engineering design process as a method of problem solving or through engineering projects providing context for the application of science and mathematics concepts. However, the framing of engineering as a subject is limited or positioned as being in the service of the other subjects, e.g. D&T English NC aims. In Marginson et al's (2013) review, for example, there was hardly any reference to engineering outside of its inclusion in the acronym STEM, the focus of reporting was mainly targeted at the treatment of science and mathematics (Marginson et al. 2013).

The lack of a clear 'go to' engineering LP definition could be problematic for teachers. Teachers are practitioners and, particularly those outside of the USA, lack a nationally agreed definition of what constitutes progression in engineering at pre-college level. While counterargument may suggest that definitions can hamper teacher and pupil creativity and conceptualisation, the findings above show that where there is no clear definition of engineering LP scholars do not add their own definitions. In these cases, a definition is left out completely.

This limitation risks a cycle of marginality emerging for pre-college engineering. The lack of scholarship further reinforcing the marginalisation of engineering as a core subject discipline.

ii) How are LPs described within the context of supporting the engineering education teaching and learning in English primary and secondary schools?

Findings show that engineering specific LPs are rare and are not widely or readily accessible to teachers. Posit that with the fact that teachers of engineering in schools are often not subject specialists which poses additional challenge of accessing plentiful quality resources and research may impact provision within the classroom (Leonardi et al. 2017). Although the data papers found no LP related to the National Curriculum for England, some progress is noted within Scottish Education. Here engineering is specifically referred to within curriculum guidance documents, where the 'application of engineering' is defined within the 'Technology' specification for pre-college learners. Within the Scottish Curriculum for Excellence and the Technologies Assessing Progress documentation there describes a series of progression statements from primary school age. ('Experiences and Outcomes | Education Scotland – Technologies' n.d.). Furthermore, the Welsh Department for Education also has reviewed the curriculum into which engineering and technology will have explicit reference ('Science and Technology: Statements of What Matters – Hwb' n.d.). These documents emerge outside the scope of this literature review, in what is termed 'grey literature' however they are worthy of note as they demonstrate the shift in practice and subsequently pedagogy that will emerge over the coming years. This may precursor academic publications in the field with a focus on LPs for engineering education in England for primary and secondary schools. The impact of this means that policy and teaching practice are not in line with research evidence and outcomes. The failure of academic researchers to previously identify this gap and respond to it through rigorous research leaves curriculum development and implementation at risk of education lacking a strong evidence-informed approach.

The US, Australia, Taiwan and New Zealand, all identify engineering more explicitly in their STEM curricula. As the status and longevity of subjects at pre-college level impacts on the extent that resources and guidance is provided for teachers for mainstream curricula inclusion, it is not surprising that engineering education suffers a lack of similar profile, particularly in England. This study identifies an area of need in particular for scholarship of engineering aligned to the NC for England. Ideally, where this can happen in tandem with Learned Societies, Industry, Government and Schools resulting in an agreed LP for engineering education, subsequent resources and teacher guidance will likely ensue. The risk of continued lack of activity in this field is the persistence of a STEM skills gap and shortage, one only further exacerbated by the gender imbalance in engineering.

The authors suggest that when located, it is evident that there are a wide range of methods used to develop, trial and measure the outcomes of science, mathematics, engineering and technology LPs. This hinders comparability of findings and hinders the way teachers can potentially select one from another for use within their setting. Furthermore, while very similar, the cognitive demands and skills of each of the STEM subjects are also different. By implication the lack of such a resource impacts on teacher professional development and school system leadership. The Department for Education derives NC through evidence-based practice and academic research, informing policy change. Statutory and non-statutory guidance offers teachers the parameters within which to work, in order to ensure a consistent and high-quality teaching and learning experience for students across the country. In tandem with this, assessment and inspectorate procedures are inherently aligned with such policies, including the way in which the Office for Standards in Education, Children's Services and Skills reports on the provision schools afford to students.

Conclusions & recommendations

The findings demonstrate that engineering education LP definitions and examples are limited within the data papers, suggesting limited opportunities for teachers or researchers to take forward ideas and thinking for adaptation, modification and/or development. Papers with a science-focus show an increased prevalence of these features. The authors recommend a systematic review of engineering education LP literature, in order to further identify and review the development of this area globally.

Where the professional development is required to enhance teacher confidence, skill and understanding of engineering, and where the establishment of 'engineering teachers' at primary and secondary school level is of interest, the authors recommend a need for one or more LPs to inform curriculum development in the English education sector. A response to such work is beginning to emerge through the heightened interest and publication of engineering education frameworks by the Royal Academy of Engineering, and where this is brought together with the wide range of STEM enrichment activities, there is basis to strengthen the availability of evidence-informed programmes, policy and professional development activity (Bianchi and Chippindall 2018; Lucas et al. 2017; Serret 2018; Bianchi and Chippindall 2016).

Finally, the authors offer four recommendations for enhancing the field:

(1) Engineering education should be recognised as a distinct subject within the NC for England, and hence purposely taught from age 4–14 years (in England some children start school at aged 4; however, the NC specifies its target age range as beginning at aged 5).
(2) Further research and evidence-based practices need to be published by educators in order to prompt wider discussion and debate in field of engineering education LPs, in particular related to their use within the English education system.

(3) Industry and education work together to ensure the progression identified at pre-college level serves to meet the needs of national and local industrial strategies beyond what has already been done.
(4) Teacher professional development and associated resources are reviewed and developed to ensure there is adequate provision for new and practicing teachers about the theoretical and practical implications of engineering education at pre-college level.

From the scoping of the literature this paper highlights that, overall, LP's in engineering education remain less reported on and less developed, than LPs in both science and mathematics. The lack of a working definition of an engineering LP may be a substantial impediment for teachers, in particular those in England, who wish to develop engineering LPs within their schools. Coupled with the lack of explicit engineering content within the English curriculum, and the lack of existing English engineering LPs and of engineering LP definitions, this paper has highlighted gaps in practice and in the literature and offered four recommendations for remedy.

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