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DOI
10.1080/03043797.2025.2532589

Publication date
2025

Document Version
Final published version

Published in
European Journal of Engineering Education

Citation (APA)
van Helden, G., van der Werf, V., Schleiss, J., & Saunders-Smits, G. (2025). FIETS: a tool for assessing the embedding of theory in engineering education intervention research. *European Journal of Engineering Education*. https://doi.org/10.1080/03043797.2025.2532589

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European Journal of Engineering Education

ISSN: 0304-3797 (Print) 1469-5898 (Online) Journal homepage: www.tandfonline.com/journals/ceee20

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To cite this article: Gitte van Helden, Vivian van der Werf, Johannes Schleiss & Gillian Saunders-Smits (23 Jul 2025): FIETS: a tool for assessing the embedding of theory in engineering education intervention research, European Journal of Engineering Education, DOI: 10.1080/03043797.2025.2532589

To link to this article: https://doi.org/10.1080/03043797.2025.2532589

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EUROPEAN JOURNAL OF ENGINEERING EDUCATION
https://doi.org/10.1080/03043797.2025.2532589

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FIETS: a tool for assessing the embedding of theory in engineering education intervention research

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ABSTRACT

Engineering Education Research (EER) is characterised as having low consensus due to its diversity of perspectives and approaches. Educational theories are important for establishing consensus as they can ground the design and analysis of educational interventions in scientific discourse. Hence, to aid EER researchers in evaluating theory use while conducting (systematic) literature reviews on educational interventions, our paper introduces a quality assessment tool: the Framework for Identifying the Embedding of TheorieS (FIETS). FIETS systematises and informs the analysis of 1) which educational theories are reported in a body of literature, and 2) to what extent these theories are embedded in the design and analysis of an educational intervention. We detail the development of FIETS over multiple iterations, explain its use, and showcase its application using a case study from an existing systematic literature review. We demonstrate the insights that can be generated and how researchers can benefit from this tool.

ARTICLE HISTORY
Received 12 March 2024
Accepted 8 July 2025

KEYWORDS
educational theory; educational interventions; learning theories; instructional design; qualitative content analysis

1. Introduction

The field of Engineering Education Research (EER) strives to generate a 'systematic understanding' (Borrego and Bernhard 2011, 19) of how educators can create conditions that foster the competencies required to solve complex contemporary problems in an increasingly globalised world. This systematic understanding requires work that is both useful, to make an impact in engineering education practice, and scholarly, to build on and advance the application of educational theory within the engineering context (Edström 2020). However, EER is still a relatively new field of research (Borrego and Bernhard 2011) originating from the engineering field and mostly shaped by scholars with an interest in education. Similar to other young and interdisciplinary research fields, EER faces several challenges. Its interdisciplinary nature leads to widely varying methodological approaches and reporting practices (Borrego 2007; Power 2021). This makes it difficult to accumulate findings and assess the effectiveness of educational approaches. Furthermore, a multitude of theories is used, often 'borrowed' from the adjacent fields of Humanities and Social Sciences (HSS), which makes generalising and reaching conclusions difficult. As a result, EER is characterised as a field

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with 'low consensus', which can be challenging for engineering educators, who naturally come from a field with a high consensus (Borrego 2007; Power 2021).

To mature the field, and improve consensus, educational theories can play an important role, as they can be used to ground the design and analysis of educational interventions and connect observations with existing scientific discourse (Goncher et al. 2023). Within EER, there are many fields of research, ranging from scholarly to practice-oriented. One example of research on practice is research on educational interventions – defined as all adaptations made to an educational design with the purpose of bringing about a change. This type of research is often conducted through the scholarship of teaching and learning. In line with other research on practice, such research commonly aims to advance teaching and learning through exploring existing findings and publicly sharing ideas and practices within the discipline (Chick 2019; Wankat et al. 2002).

Notwithstanding significant works that showcase instances of deep theoretical understanding in the EER field (e.g. Mathis et al. 2017), there are issues with how theories are used in EER, and especially in research on practice. The overall engagement with, understanding of, and development of new theories in EER still has significant room for improvement. Literature reviews in EER and related fields, such as STEM education and computing education, suggest that educational theories are generally only used in superficial ways, and in particular, intervention studies are not well embedded in educational theories (Reinholz, White, and Andrews 2021; Wankat 2004). Thus, there is a need to take a close look at the use, understanding, and development of theory in EER, as is underlined in a recent publication by Beddoes (2022) who states that: '*Compared to some other Humanities and Social Science (HSS) fields, theory use in EER has dominantly been conceptualized, mobilized, and circumscribed in relatively narrow and limited ways, when it is engaged at all, which it often is not. Moreover, there has been no sustained concern or conversation about this fact.*' (Beddoes 2022, 180).

In her critical reflections, illustrated with clear examples of the problems on how theory is used and understood in EER, some of the key risks of not engaging in discourse over theory and theory forming she highlights are: (a) it limits the lens of the researchers to '*what is seen, known, and understood*', (b) there is limited theory development, and as a result, also limited intellectual growth of EER, and (c) a '*shared understanding or consensus*' of what is going on in the field in relation to theory does not exist/is missing (which is common practice in HSS fields).

It is, therefore, important to take a critical look at the use of theories when analysing EER literature. Previous research in Engineering Education has already proposed tools aiming to systematically investigate whether theories are mentioned and what theories are most used in EER (Borrego et al. 2013; Malmi et al. 2018; Wankat 2004; Williams and Neto 2012). However, to understand and improve the embedding of theories in studies of educational interventions, there is a need to also understand *how* theories are used in studies in EER. Systematic literature reviews can contribute to this question. To help researchers enhance the quality of their analysis in these reviews, this paper introduces a quality assessment tool similar in aim to tools such as ROBIS (Whiting et al. 2016) and AMSTAR (Shea et al. 2007), which are used to evaluate contributions in the medical field.

In particular, our paper reports on the development and use of this quality assessment tool to aid researchers in EER in *evaluating the use of theory* when conducting literature reviews on practice research in the field of EER. This tool, which we have named FIETS – **F**ramework for **I**dentifying the **E**mbedding of **T**heorie**S**, focuses on the questions of (1) which educational theories are mentioned, and (2) the extent to which these theories inform (a) the design of an educational intervention and (b) the analysis of that educational intervention.

Furthermore, we will show that FIETS can be applied to systematically analyse a body of intervention literature within EER by analysing studies from a recently published systematic literature review as an example. FIETS can be used to systematically assess EER practice research literature as to what theories and theory-derived frameworks have been reported. Therefore, it can support researchers who are working with, or wish to work with, educational theory to better value the contribution of individual articles to their research question when doing (systematic) literature reviews. In addition, FIETS can help to generate data to come to conclusions on how and to what extent theories and subsequent frameworks are reported in EER practice literature, thus guiding the much-needed discourse on the use of theory and theory development among researchers and practitioners to work towards a greater level of consensus in the EER field (Beddoes 2022; Borrego, Foster, and Froyd 2015; Power 2021).

Before presenting FIETS (Section 4), we first reflect on the use of theory in EER research (Section 2). Next, we present the development of the tool (Section 3), the tool itself and how to use it (Section 4), followed by a case study (Section 5), which shows its potential use and how the results generated using the tool can inform the advancement of theoretical understanding in EER. For the case study, we focus on educational theories expressed in research on interventions in collaborative engineering design education (van Helden et al. 2023). We conclude the paper by highlighting the implications and addressing the limitations of our work (Section 6).

2. The use of theory in EER

Over the years, multiple scholars have systematically analysed the use of educational theory in EER interventions. An early work provides an analysis of the first 10 years of the Journal of Engineering Education (1993–2002), including a reflection on the use of educational theory (Wankat 2004). Findings indicate that '*a reasonable amount of papers*' refer to educational theories, however, less than 20 percent actually used these theories for the design or analysis of their study. Williams and Neto (2012) compared engineering education studies with a focus on educational technologies published in two EER journals: IEEE Transactions on Education and Advances in Engineering Education. They classified studies on multiple dimensions, including one on different manifestations of theory, and concluded that respectively 62% and 73% of the selected studies demonstrate some connection with previous research. Borrego and colleagues (2013) conducted a systematic literature review, in which they investigated to what extent theory from industrial and organisational psychology is used in team-based engineering education interventions. When analysing their body of literature, they found that articles regularly cite educational literature. However, as educational literature was not the focus of their work, they only provide an overview of cited literature and do not address what type of educational theories were used or how these theories informed the design and analysis of interventions. More recent research by Malmi et al. (2018) investigated research processes in the EER field. This work analyses 155 articles published in the European Journal of Engineering Education and concludes that 72% of the papers used some form of an '*explanatory framework*', which they defined as the '*theoretical or conceptual foundations*' (Malmi et al. 2018, 175) of a paper. A total of 128 different 'explanatory frameworks' were identified, which indicates the use of a great diversity of theories. Through thematic clustering, Malmi et al. (2018) distinguished 19 types of '*explanatory frameworks*'. The most popular among these are theories of learning and cognitive development (e.g. constructivism), models for learning as a social process, and models underlying specific types of science/engineering curricula (e.g. problem-based learning). These previous studies all indicate that the majority of studies in EER use references related to educational theory. However, most of these studies do not provide insights into whether and how these theories are used. Only Wankat (2004) reflects on theory embedding by noting that, although many papers mention educational theories, only a few use these theories to inform the design or analysis of their study. This may be an indication that, even though educational theories are mentioned, they are only used in a shallow way.

In the field of Computer Education Research (CER), authors' systematic investigations on the extent to which educational theories were used led to similar observations. Here, Malmi is an active researcher on theory use, whose work includes research on the use of (domain) specific theories (Malmi et al. 2020, 2022) and general educational theories (Malmi et al. 2014). Concerning the latter, Malmi and colleagues (2014) investigated the use of theory in 308 CER papers that were published between 2005 and 2011 and concluded that 80% did not build on theoretical research from education, and nearly half of the research did not build on any theory at all, irrespective of the original discipline. The work of Szabo et al. (2019) and Szabo and Sheard (2022) moves beyond identifying whether and which theories are mentioned, as they investigate the co-occurrence of theories. Szabo et al. (2019) identified three main groups of theories that co-occurred often, namely: social theories, experiential theories, and theories of mind. Szabo and Sheard (2022) further developed this work. First, they expanded the main groups of theories to a number of six, including behaviourist and cognitivist learning theories, working memory theories, social cognition theories, motivation learning theories, behaviourist and cognitivist meta-theories, and specific computing education learning theories. Second, for specific computing education learning theories, they analysed the connection between theories. For this, they developed a taxonomy that distinguishes between learning theories that are causally referenced, separately discussed, together discussed, critically compared, part of the analysis or design of the intervention/design of artifacts, and theory development. They found that the majority of connections between theories were only shallow.

Both in EER and CER, scholars have pointed to another difficulty. That is, there is discussion on what can be defined as a 'theory' (Goncher et al. 2023; Szabo et al. 2019; Tedre and Pajunen 2022). In the field of educational sciences, there is an ongoing scientific discourse in which some scientists (e.g. Reigeluth 1983) would argue that instructional design models should be categorised as educational theories, however, this is not a generally accepted view. Chapter 7 of the International Handbook of Engineering Education Research (Goncher et al. 2023) presents a list of theories that have been identified to date as having been applied in the fields of Computer and Engineering Education based on the studies by Hingle et al. (2022) and Szabo et al. (2019). Interestingly, here, problem-based learning is listed as a theory identified in EER thus indicating its acceptance as a theory in education, but the umbrella term *Collaborative learning* which includes all instructional approaches to learning in small groups including problem-based learning (Yang 2023) is not, nor are many other instructional approaches, such as design-based learning or service learning. When referring to theories in this paper, we follow the broad definition of theory introduced by Malmi et al. (2014): '*We define 'theory' to mean a broad class of concepts that aim to provide a structure for conceptual explanations or established practice, and use such terms as 'theories', 'models', and 'frameworks' to describe particular manifestations of the general concept of theory*' (Malmi et al. 2014, 29).

To summarise, the lack of proper understanding of the concepts of theories and frameworks combined with their superficial and incongruent reporting in EER literature is problematic. It risks bias, incorrect interpretations of results, and continued occurrence of this issue could end up limiting the development of theories and the development of the field as Beddoes (2022) argued. To avoid these misconceptions and misunderstandings perpetuating themselves, existing literature must be critically assessed on how theories and their frameworks are used when studying literature. Hence, a logical next step would be, that when reviewing literature for the use of theory, a more detailed systematic approach is taken when analysing the potential contribution of an article. This approach should not only look at identifying what theories and theory derived-frameworks are reported in an article, but also at how these are used to better assess the contribution of the literature to the problem that is being studied.

3. Tool development

In this section, we explain how we developed FIETS. Literature on methodology to develop instruments for assessing quality of papers reveals that these only appear to exist in the medical field to improve the assessment quality in systematic literature reviews. This is not strange as systematic literature reviews stem from the medical field and the order of magnitude of the number of systematic literature reviews published to date in that field is much larger compared to other fields (Slebodnik, Pardon, and Hermer 2022). Their guidance documents are generally all developed iteratively, by a team of multiple people, with input from experts as is documented for instance in Whiting et al. (2016) on the development of the ROBIS tool. Hence, a similar iterative approach was followed in the development of FIETS (see below), with the major difference being that no formal expert panel was gathered but that generous use was made of the input from the community when an iteration was

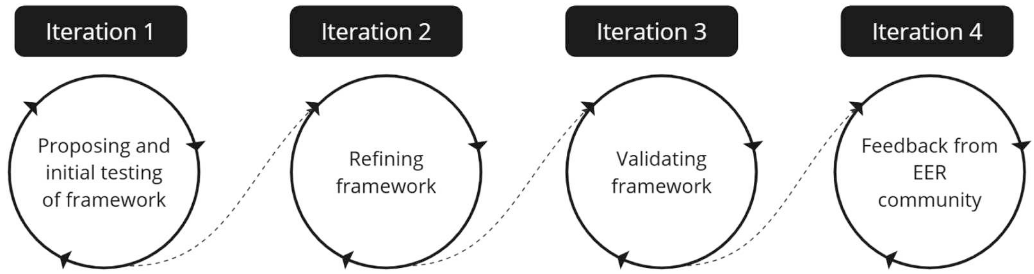

Figure 1. Overview of development iterations of FIETS.

presented at an engineering education conference. In addition, feedback received during the review process of this paper contributed greatly to the iterative refinement of FIETS as a tool.

Once developed, FIETS has to be able to (1) identify *what* – if any – theories and or subsequent frameworks are mentioned in a research article on engineering education practice and (2) analyse *how* the theories mentioned were used.

To develop FIETS, we used an iterative design development procedure, based on a selected set of papers from a review paper, to shape the initial design of FIETS. The iterative approach aimed to refine FIETS through internal discussions of the author team and external expert feedback to become a tool that can be applied universally to EER practice research. The design included four iterations, as summarised in Figure 1.

3.1. Selection of literature

FIETS was initially generated and tested using intervention studies derived from the specific context of collaborative engineering design. More specifically, we used a body of literature derived from a prior systematic literature review on intervention studies in collaborative engineering design education (van Helden et al. 2023). This review adhered to the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines (Page et al. 2021) and encompasses 111 studies. Although we designed FIETS to be universally applicable to EER literature, we started our development by selecting the topic of interventions in engineering design as a starting point to develop FIETS since (1) design is a core activity in the engineering domain (Dym et al. 2005) and (2) intervention studies are commonly found in EER due the applied nature of the field. From this pool of studies, we randomly selected 18 articles, six for the initial development and testing of our tool and twelve for the creation of a case study to showcase the initial tool. We used a manual coding process.

3.2. Design iteration 1

As the tool first needed to identify *what* theories were used, theory identification was the first step. To meet the second requirement of identifying *how* the theories were used in the paper, the second author proposed an initial set of criteria for FIETS to indicate where the identified theories were mentioned in the paper and how they were embedded in that area of the paper. The three initially defined areas in the paper were:

(1) the background – covering the introduction and related work,
(2) the (intervention's) design – covering the methods,
(3) the (intervention's) analysis – covering the results, discussion, and conclusion.

For each area, a dedicated scale was designed by the second author, using descriptive criteria, allowing a coder to score each paper on the level of detail in which theories were mentioned.

The purpose of these scales was to assess the use of theories in a paper, and thus to meet the third criterion of the tool: an ability to value how the theories were used in the paper. For the background, four scale items (0-3) were designed to rate the extent to which theory was mentioned (see Section 4), for the (research) design three scale items (0–2) were designed, and for the analysis, five scale items (0–4) were conceived. The basis for each scale was defining the two ends of each scale: what should be the most desired way of reporting on theories as suggested by many textbooks on research in education such as Cohen, Manion, and Morrison (2007) (high end of scale) and not reporting on theories at all (low end of scale). After that, descriptive scale items to cover the range of possible incomplete reporting between those two ends were developed. Each scale had a scale item that scored 0 to indicate that the theory was not mentioned in that area of the paper.

This tool allowed a coder to begin by first identifying and highlighting all educational theories mentioned in a paper. Subsequently, the coder evaluated three separate scales with predefined criteria that assess the extent to which the identified educational theories are integrated into three defined key areas of the selected paper. In a collaborative session among the first three authors, the scales were refined. The proposed tool was then tested by three coders (first three authors), who all independently coded the same three randomly selected articles of the selected sample (Demara et al. 2017; Du et al. 2020; Teiniker, Paar, and Lind 2011). The initial coding results (i.e. the evaluation of the scales) were compared and any disagreements and discrepancies were resolved through discussion. For example, we identified ambiguity in the 'embedding in background' scale, where our initial attempt was to differentiate between articles offering solely a theory definition and those providing additional explanations or examples. As a result, we merged these distinctions.

3.3. Design iteration 2

The updated tool was then tested by the same three authors, who independently coded three additional randomly selected papers from the literature selection (Alorda, Suenaga, and Pons 2011; Ardaiz-Villanueva et al. 2011; Baumann 2020). During the comparison of results from the second iteration, we identified disparities among coders regarding what should be classified as an educational theory, reflecting the overall discourse around this topic. To mitigate this issue in future coding, we decided to include a list of the most frequently mentioned educational theories in EER. To align our work with research in the EER field, we used the list compiled by Goncher et al. (2023) in the most recent version of the International Handbook of Engineering Education Research. To ensure a consistent and systematic approach, an additional step in the workflow was introduced: When a coder encountered a potential educational theory not present on the initial list, they consulted with other coders and/or education literature to determine if it should be included as an additional eligible educational theory for coding. This reflects the various manifestations of theories.

3.4. Design iteration 3

After incorporating these adjustments into the tool, a first validation of the tool and the coding workflow was conducted, where three raters (authors) coded a total of 12 additional papers randomly selected from van Helden et al. (2023). These 12 papers cover 10 percent of the complete study, which is a common approach for validation based on a smaller sample (Campbell et al. 2013; O'Connor and Joffe 2020). Each of these papers was independently coded by two raters. Next, *intercoder agreement* (Campbell et al. 2013), in which two or more coders reconcile through discussion coding discrepancies they may have for the same unit of text, was reached. The third rater was also involved in this process to provide additional feedback and validation. The selected 12 papers are: (Akintewe, Gaines, and Small 2019; Clavijo and Pochiraju 2019; Greetham and Ippolito 2018; Heylen, Buelens, and Vander Sloten 2010; Jensen, Utriainen, and Steinert 2018; Lara-Prieto et al.

2020; Mabley, Ventura-Medina, and Anderson 2020; Nolen and Koretsky 2018; Qamar et al. 2016; Santoso, Sharfina, and Sadira 2018; Tomkinson and Hutt 2012; Volpentesta, Ammirato, and Sofo 2012). The tool itself and preliminary results from using the tool for coding were presented at an EER conference (van der Werf et al. 2023). The results highlighted that the tool can be used to detect a variety of insights into how theory is used within intervention studies.

3.5. Design iteration 4

The presentation of the validated tool within the EER community resulted in feedback that enabled further improvement of the tool and its usefulness. Iteration 4 addresses this community feedback and the elaborate feedback from reviewers of this article. Two major points of feedback focusing on the context and analysis of the results emerged. Firstly, it was suggested to clarify the positioning of the tool. We originally presented FIETS as a tool for assessing *theoretical embedding* in *general* engineering education research papers. We now clarified this position, with FIETS being a tool specifically aimed at assessing *the quality of the use of theories* in literature reporting on *practice research*, such as research on educational interventions, as this better describes its purpose. A second point of feedback was to add a categorisation of the type of educational theories identified to add an additional layer of interpretation and provide a context to the theories found. However, as is evident from the literature discussed earlier (Goncher et al. 2023; Reigeluth 1983; Szabo et al. 2019; Tedre and Pajunen 2022), there is no agreement on what a theory is let alone a classification of educational theories. The development and acceptance by the research community of such a classification is a project well beyond the scope of this paper and the expertise of the authors. As such, we decided that adding a classification of theories would currently not add value given the current lack of consensus and should therefore be considered a desirable feature for upcoming iterations once such consensus is reached. Finally, during the fourth phase, we also named our tool for easier reference: FIETS.

4. Introducing FIETS: framework for identifying the embedding of theories

FIETS is an analytical tool designed to support the analysis phase of (systematic) literature reviews and assess the embedding of theories. The core of FIETS consists of a workflow and three scales. The tool and associated data are made available via the 4TU.ResearchData repository (van Helden et al. 2024).

4.1. Workflow

The workflow of coding to identify the embedding of theories consists of two phases, as shown in Figure 2. The first phase involves identifying all educational theories mentioned in the paper based on the initial list or potentially adding additional theories. The second phase focuses on rating the

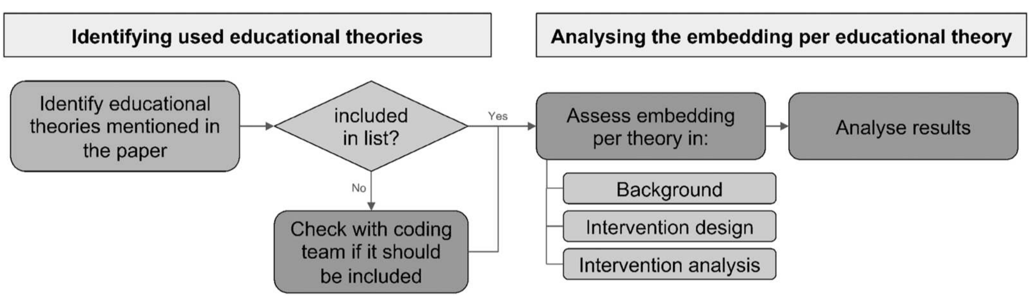

Figure 2. Workflow of identifying and assessing embedding of educational theory, adapted from van der Werf et al. (2023).

extent to which these educational theories are integrated into the paper. Based on the initial validation in design iteration 3, this workflow produces consistent and reliable coding results.

4.2. Scales

For each paper, a coder evaluates the embedding of all identified theories across four aspects: (1) background, (2) design of the intervention, and (3) analysis of the intervention. For all aspects, different scales represent the extent to which an educational theory is integrated into the study. The scales per aspect with corresponding numerical code are shown in Table 1. A detailed codebook, including an explanation of all scales with examples can be found in Appendix A.

In the background scale (applied to the introduction and related work sections of a paper), we identify four categories that allow us to distinguish whether an educational theory was (a) not mentioned, (b) mentioned, but no reference for this theory was provided, (c) mentioned including a reference, yet no additional information that clarified the theory was provided, or (d) mentioned including a reference and additional clarification (e.g. a definition, explanation, or example relating to the educational theory).

In the intervention design scale (applied to the methods section of a paper), we distinguish whether an educational theory was (a) not mentioned, (b) mentioned, but no explicit connection was made between the theory and the design of the intervention, or (c) mentioned and an explicit connection was made between the theory and the design of the intervention. With 'explicit', we mean that it should be stated how the design of an intervention was guided by the educational theory mentioned.

In the intervention analysis scale (applied to the results, discussion, and conclusion sections of a paper), we created five distinct categories to distinguish whether an educational theory was: (a) not mentioned, (b) mentioned, but no explicit connection was made between the theory and the analysis of the intervention, (c) mentioned and an explicit connection was made between the theory and the analysis of the intervention, yet no connection with practical or theoretical implications was made, (d) mentioned and an explicit connection was made between the theory and the analysis of the intervention from which practical implications were derived, and, finally, (e) mentioned and an explicit connection was made between the theory and the analysis of the intervention from which theoretical implications that lead to the advancement of educational theory were derived. We consider a connection to be 'explicit' when it is stated how a specific finding is related to the educational theory mentioned. We consider something to be a 'practical implication', when the potential value of a finding for engineering education practice is stated. We consider something a 'theoretical implication' when the educational theory that is reported is advanced with the help of the study's findings, for example through introducing a new theoretical model or extending one.

5. How to use FIETS – a case study

To demonstrate the effectiveness of FIETS in providing insights into how educational theories are used, we conducted a case study using a subset of 12 papers from an exemplary literature review on representative intervention studies (van Helden et al. 2023) (refer to Design Iteration 3 for details). The complete overview of the results of our analysis is shown in Table 2. In the next sections, we will showcase how these results can be used to identify (1) mentioned theories, (2) the embedding of these theories in the design and analysis of an intervention, and (3) the use of these theories throughout a paper. We will outline how the data derived from the use of FIETS can be presented and analysed in a way that is both informative and scalable for making relevant conclusions in literature reviews that incorporate a large body of intervention studies. The research questions we aim to answer in this case study using FIETS include:

- What educational theories are presented?

- To what extent are educational theories used in the background of the work?
- How is an educational theory used to inform the design of the intervention?
- How is an educational theory used to inform the analysis and evaluation of the intervention?
- How is educational theory used throughout the paper?
- Are theories refined or advanced based on specific intervention/practice outcomes?

5.1. Identified theories

First, we analyse the educational theories and theory-derived frameworks that were mentioned. In our sample, each article mentioned at least one theory. In Table 2 (first two columns), we can observe that 44 theories were mentioned, of which 22 were unique. The most popular theories were project-based learning, active learning, and collaborative learning.

Notably, only seven out of the 22 unique theories were mentioned in the list compiled by Goncher et al. (2023) for the International Handbook of Engineering Education Research. This might be partially due to a difference in the definition of what can be considered a theory, as we decided to take a broad approach and also include manifestations of theory, such as models and frameworks. However, it can also indicate that the use of educational theories in EER is broader than found in previous studies.

5.2. Embedding of educational theories in intervention

Next, we assess the extent to which the mentioned educational theories and theory derived-frameworks are embedded in the background, intervention design and intervention analysis. It should be noted that the results from FIETS can be presented and interpreted at different levels, which each reveal different aspects of theory embedding and therefore can be used to draw different types of conclusions.

First, we can look at the data on a *theory-level* (Table 3). This means that for each of the 44 identified theories, we only look at how they score on each scale to present totals per score per scale. Aggregating the data on this level allows for drawing conclusions on, for example, how reported theories are spread over the different parts of a paper. Note that this level does not look at individual theories or summarise data for specific educational theories, i.e. project-based learning (see Section 5.3).

Second, we can look at the data on a *paper-level,* or the level of *analysed papers* (Table 4). This means that for each of our 12 papers, we only look at the highest score they received on a scale, independent of which reported theory this score is connected to. Aggregating the data based on the highest score per paper per scale allows for drawing conclusions on, for example, whether the design or analysis of an intervention is grounded (well) in at least one educational theory or theory-derived framework. Another similar measure could be to look at the lowest score per paper (not included here).

5.2.1. Background (Scale 1)

From Table 3, we can infer that, of the 44 identified theories, 33 are mentioned in the background section, while the remaining 11 were mentioned only in the design or analysis of an intervention. Of the 33 theories mentioned in the background, 10 do not include any reference to the theory. Another 9 theories are referenced, but no additional clarification is given. Only 14 theories are mentioned with both a reference and a definition, an explanation, or an example to clarify the theory.

When analysing the embedding of theories in the background on a paper-level (Table 4), we see that all the papers from our sample mention at least one theory in their background section. However, three papers do not provide a reference for any of these theories, while another three papers provide at least one reference for a mentioned theory, but not one additional clarification. The remaining six papers contain additional clarification for at least one reported theory.

Table 1. Scales for rating the embedding across different aspects of the paper. Theory here refers to educational theory. A filled (black) circle, ●, refers to the position in the scale, whereas an empty (white) circle, ○, refers to the scale maximum. It is important to note that a filled circle in one scale does not possess the same weight as one from another scale, hence a total score per paper (adding up all filled circles) does not convey meaning when comparing this to other papers.

Scale 1 **Background**	○○○ not mentioned	●○○ mentioned without reference	●●○ mentioned with reference but no additional information	●●● mentioned with reference, and additional definition, explanation, or example	
Scale 2 **Intervention design**	○○ not mentioned	●○ mentioned but not explicitly connected with the design	●● explicitly connected with the design		
Scale 3 **Intervention analysis**	○○○○ not mentioned	●○○○ theory is mentioned but not explicitly connected with results of the research	●●○○ theory is explicitly connected with results of the research	●●●○ practical implications with relation to the theory are derived from the results	●●●● theoretical implications: theory is advanced

Table 2. Overview of theories mentioned in the selection of papers. The extent of their embedding is indicated by the score on each scale behind each paper.

Theory	N	Background		Intervention Design		Intervention Analysis	
project-based learning	8	Clavijo and Pochiraju 2019	●●○	Clavijo and Pochiraju 2019	●○	Jensen, Utriainen, and Steinert 2018	●○○○
		Heylen, Buelens, and Vander Sloten 2010	●○○	Lara-Prieto et al. 2020	●○	Santoso, Sharfina, and Sadira 2018	●○○○
		Jensen, Utriainen, and Steinert 2018	●○○	Santoso, Sharfina, and Sadira 2018	●●	Volpentesta, Ammirato, and Sofo 2012	●●○○
		Mabley, Ventura-Medina, and Anderson 2020	●●○	Volpentesta, Ammirato, and Sofo 2012	●●		
		Qamar et al. 2016	●●○				
		Santoso, Sharfina, and Sadira 2018	●●●				
		Volpentesta, Ammirato, and Sofo 2012	●●●				
active learning[a]	5	Greetham and Ippolito 2018	●●●	Santoso, Sharfina, and Sadira 2018	●○	Mabley, Ventura-Medina, and Anderson 2020	●●○○
		Lara-Prieto et al. 2020	●○○				
		Mabley, Ventura-Medina, and Anderson 2020	●●●				
		Qamar et al. 2016 (*only in abstract*)	●○○				
collaborative learning[a]	5	Clavijo and Pochiraju 2019 (*only in abstract*)	●○○	Santoso, Sharfina, and Sadira 2018	●○	Santoso, Sharfina, and Sadira 2018	●●○○
		Lara-Prieto et al. 2020	●○○				
		Qamar et al. 2016	●●●				
		Santoso, Sharfina, and Sadira 2018	●●●				
		Volpentesta, Ammirato, and Sofo 2012	●●○				
problem-based learning	3	Greetham and Ippolito 2018	●●○	Mabley, Ventura-Medina, and Anderson 2020	●●	Mabley, Ventura-Medina, and Anderson 2020	●●●○
		Mabley, Ventura-Medina, and Anderson 2020	●●●			Tomkinson and Hutt 2012	●●○○
		Tomkinson and Hutt 2012	●●○				
cooperative learning[a]	2	Akintewe, Gaines, and Small 2019	●●●	Akintewe, Gaines, and Small 2019	●●		
		Volpentesta, Ammirato, and Sofo 2012	●●○				
experiential learning	2	Volpentesta, Ammirato, and Sofo 2012	●○○			Tomkinson and Hutt 2012	●●○○
flipped classroom[a]	2	Greetham and Ippolito 2018	●○○	Clavijo and Pochiraju 2019	●●	Clavijo and Pochiraju 2019	●○○○
		Clavijo and Pochiraju 2019 (*only in abstract*)	●○○				
social constructivism	2	Greetham and Ippolito 2018	●●●	Mabley, Ventura-Medina, and Anderson 2020	●●		
		Mabley, Ventura-Medina, and Anderson 2020	●●●				
team-based learning[a]	2	Greetham and Ippolito 2018	●●●	Greetham and Ippolito 2018	●●	Greetham and Ippolito 2018	●●●○
		Qamar et al. 2016	●●●				
achievement goal orientation	1					Mabley, Ventura-Medina, and Anderson 2020	●●○○
blended learning	1	Tomkinson and Hutt 2012	●○○	Tomkinson and Hutt 2012	●○	Tomkinson and Hutt 2012	●●●○
bridging epistemologies	1					Nolen and Koretsky 2018	●○○○
challenge-based learning	1	Lara-Prieto et al. 2020	●○○				
constructive alignment	1	Mabley, Ventura-Medina, and Anderson 2020	●●●				
constructivism	1	Volpentesta, Ammirato, and Sofo 2012	●○○				
flow (engagement theory)	1	Nolen and Koretsky 2018	●●○			Nolen and Koretsky 2018	●●○○

(*Continued*)

Table 2. Continued.

Theory	N	Background		Intervention Design		Intervention Analysis	
group-based learning	1	Tomkinson and Hutt 2012	●○○			Tomkinson and Hutt 2012	●●○○
knowledge building theory[a]	1					Nolen and Koretsky 2018	●○○○
self-regulated learning[a]	1					Santoso, Sharfina, and Sadira 2018	●●○○
service learning	1	Akintewe, Gaines, and Small 2019 (*only in abstract*)	●○○	Akintewe, Gaines, and Small 2019	●○		
situated learning	1	Mabley, Ventura-Medina, and Anderson 2020	●●●	Mabley, Ventura-Medina, and Anderson 2020	●●	Mabley, Ventura-Medina, and Anderson 2020	●●●○
social-cultural theory[a]	1	Mabley, Ventura-Medina, and Anderson 2020	●●○				

[a]*Theory mentioned in list of theories* (Goncher et al. 2023)

Table 3. Results from FIETS: number of identified (reported) theories per score per scale (total number of reported theories is 44).

Scale 1 **Background**	○○○ 11	●○○ 10	●●○ 9	●●● 14	
Scale 2 **Intervention design**	○○ 30	●○ 6	●● 8		
Scale 3 **Intervention analysis**	○○○○ 26	●○○○ 5	●●○○ 9	●●●○ 4	●●●● 0

Table 4. Results from FIETS: number of papers represented per highest score per scale on a paper-level (total papers is 12).

Scale 1 **Background**	○○○ 0	●○○ 3	●●○ 3	●●● 6	
Scale 2 **Intervention design**	○○ 4	●○ 2	●● 6		
Scale 3 **Intervention analysis**	○○○○ 4	●○○○ 2	●●○○ 3	●●●○ 3	●●●● 0

5.2.2. Design of intervention (Scale 2)

Table 3 shows that a total of 14 educational theories and theory-derived frameworks are mentioned in the sections that describe the design of educational interventions. For a clear majority (30), theories do not occur in the sections related to the design of an educational intervention.

However, at a paper-level (Table 4), we can see that 6 out of 12 articles grounded the design of their learning activity explicitly in at least one educational theory. Another two articles only mention one or more theories but fail to connect this theory to the design of their intervention. Finally, four articles do not mention any educational theory when describing the design of their intervention, which is notable, especially since a more detailed analysis reveals that these articles combined mention a total of 9 theories, of which 7 unique, in other parts of their article (Table 2 and Table 5).

5.2.3. Analysis of intervention (Scale 3)

In Table 3, we observe that a total of 18 educational theories and theory-derived frameworks are mentioned in the sections on the analysis of an intervention. Like Scale 2, the majority of theories (26) mentioned in our sample of papers do not occur in the analysis of educational interventions.

Table 5. Highest score on each category per paper per scale (any theory).

Paper	Background	Intervention Design	Intervention Analysis	Unique theories
Akintewe, Gaines, and Small 2019	●●●	●●	○○○○	2
Jensen, Utriainen, and Steinert 2018	●○○	○○	●○○○	1
Clavijo and Pochiraju 2019	●●○	●●	●○○○	3
Greetham and Ippolito 2018	●●●	●●	●●●○	4
Heylen, Buelens, and Vander Sloten 2010	●○○	○○	○○○○	1
Lara-Prieto et al. 2020	●○○	●○	○○○○	5
Mabley, Ventura-Medina, and Anderson 2020	●●●	●●	●●●○	8
Nolen and Koretsky 2018	●●○	○○	●●○○	3
Qamar et al. 2016	●●●	○○	○○○○	4
Santoso, Sharfina, and Sadira 2018	●●●	●●	●●○○	4
Tomkinson and Hutt 2012	●●○	●○	●●●○	4
Volpentesta, Ammirato, and Sofo 2012	●●●	●●	●●○○	5

On a paper-level (Table 4), we see that half of the papers (6) in our sample either do not mention any theory (○○○○) or make no connection between theory and their result (●○○○). Three papers connect their results with at least one educational theory but do not use that theory to derive implications for practice. The remaining three papers do present practical implications, but none of the 12 papers directly contributed to the advancement of existing theory in the context of the engineering education domain.

5.3. Use of individual theories throughout papers

For a more detailed analysis of the use of theories throughout papers, we also investigated the extent to which the mentioned theories are used consistently throughout papers (Table 2). For this step, each of the 44 mentions of theories is analysed for when and where it was used in a paper.

In our sample, it rarely occurs that an educational theory is embedded in each section of a single paper. Still, there are some exceptions, such as the work of Mabley, Ventura-Medina, and Anderson (2020), in which situated learning theory was introduced, used to ground the intervention, and connected with the results to derive practical implications. It must be noted that for an educational intervention study, it is not necessarily required that a theory re-occurs in each section. Different types of educational theory can have different purposes: some might only be useful for designing an intervention and not fit the intervention analysis section. Nevertheless, investigating the consistency of theory use can lead to observations that are not in line with the expected structure of a paper. For example, in our sample, we encountered papers introducing theories in their background section that are never connected to their intervention design or intervention analysis, as well as multiple occasions where theories were used in the intervention design or intervention analysis (e.g. Clavijo and Pochiraju 2019; Nolen and Koretsky 2018) that were never introduced earlier in their paper.

A further analysis could be interesting to compare two or more educational theories, taking into account that not all theories can or should be used in all sections of a paper. However, this type of comparison also requires a detailed analysis of specific patterns to be meaningful, as well as a larger sample set than is currently included.

5.4. Case study conclusions

In line with previous systematic reviews on the integration of educational theory in EER (Borrego et al. 2013; Malmi et al. 2014; Williams and Neto 2012), it was found that educational theories are mentioned often. Every paper in our sample mentioned at least one educational theory or theory-derived framework, leading to the mentioning of 44 theories in total.

When assessing to what extent these educational theories or theory-derived frameworks are embedded in the background, design of an analysis, or analysis of an intervention, however, our results points to a problem similar to the one identified by Wankat (2004) two decades ago: many authors do not deeply engage with educational theory. On a theory-level, it was found that most theories that were mentioned in the papers appeared in the background section (33), yet only 14 were introduced with a reference and additional clarification. Even more, most of the theories that were mentioned did not appear in either the intervention or the analysis section.

On a paper-level, it was found that the design of only half of the analysed interventions was explicitly grounded in theory. This indicates that, even though each paper mentioned at least one educational theory, e.g. in the background section, these theories very often did not play a(n explicit) role in informing the design of an intervention, or if they did, it was not reported. Similar findings occurred for the analysis of the interventions. Here, only half of the papers made an explicit connection between their results, findings, conclusions, and educational theories. These findings indicate that very often, theory is not used to interpret results and that results are not used to engage in theory building.

In addition, we can observe that theories are not consistently mentioned throughout papers. This is not necessarily a problem, as different theories might serve different purposes. Yet, our findings do reveal unusual structures that might indicate shallow use of theory. An example is the introduction of a theory in the background section that is not connected to either the intervention design or intervention analysis. Although theories can be used to frame a paper, it can be wise to question the additional value of mentioning these theories if they do not further (explicitly) inform practice or analysis. A deeper investigation of the patterns in which (certain specific) theories are used throughout papers that introduce or evaluate educational interventions, could help shed light on this issue.

5.5. Reflection on the use of FIETS in the case study

Although our analysis only considered a case study consisting of a small subset of papers, we can already observe what type of conclusions can be derived about the current state of educational theory in EER by using FIETS. FIETS enables us to draw conclusions on the number of different theories mentioned, in which part of the paper the theories were mentioned, and the extent to which theories are used and connected throughout the papers.

6. Discussion & conclusions

This study aims to present the design and showcase the use of FIETS, a tool that not only provides insights into which educational theories are reported in engineering education intervention studies but also assesses the extent to which these theories are used to inform the design and analysis of interventions. In our case study (Section 5), we demonstrated how to use FIETS and how it may be useful to researchers doing a literature review on interventions in EER by applying it to a subset of papers that described educational interventions that involved collaborative engineering design. In the following paragraphs, we will elaborate on the limitations of FIETS in its current state and opportunities for future work.

6.1. Limitations

Although FIETS is intended as a tool to analyse various bodies of EER practice research, it was developed using only a particular type of intervention, namely interventions that involved collaborative learning in the context of engineering design activities. When analysing different subsets of EER practice literature or even literature from adjacent fields such as CER, it may be possible that the tool requires some adaptations. For example, in CER, many domain-specific theories are used that could potentially play a significant role in informing the design and analysis of interventions (Malmi et al. 2014, 2022). In that case, relevant domain-specific theories related to education should be included in the list of theories, to assure that relevant theories become noticed. For this reason, we argue that FIETS should be viewed as a tool to be adapted when appropriate, for example, to adjust for needs in other fields or to add upon the tool to deepen its possibilities regarding the interpretation or analysis of results (see below). Its development will benefit from being tested and adjusted or extended using different types of educational interventions including those from related educational research fields. We invite researchers and practitioners from the EER community and beyond as co-creators in this endeavour.

In addition, the community feedback during an EER conference revealed a need for a classification of different types of educational theories to aid practitioners and practice-oriented researchers in finding their way. This would help, for example, practitioners and researchers to differentiate between more general theories of cognition (e.g. cognitivism, constructivism) and more specific theories or models targeting, for example, phenomena from educational psychology (e.g. self-regulated learning theory), instructional design (e.g. problem-based learning), or curriculum design. Next to being a welcome addition to the education community as a whole, by creating more structure and overview in education theories, such a classification would be a useful addition to FIETS, as it would enable its users to reveal what type of theories are used predominantly in a subset of literature and which type of theories remain underexplored. However, currently, no generally accepted division of types of educational theories appears to exist or be under development.

Lastly, in our scales, we use whether a paper uses a reference to introduce a theory as an indicator. However, this does not tell anything about the quality of these references. As such, FIETS in its current form cannot be used to make a judgment on whether used references were appropriate.

6.2. Future work

The authors intend to develop FIETS further and want to do so collaborating with the wider EER community and related fields to enhance its useability. To develop FIETS into a robust quality assessment tool for the use of theories in intervention studies in engineering education and wider afield FIETS needs to be assessed for its suitability for use in related fields, such as CER and the emerging field of Artificial Intelligence education (Schleiss et al. 2023). CER, similar to EER, is a young and interdisciplinary field, in which researchers have voiced their concerns about a lack of deep engagement in educational theory (Malmi et al. 2014). Grounding the scientific discussion is particularly important in quickly expanding research communities such as the field of AI Education to avoid fast-paced publications with little theoretical grounding. Finally, FIETS' potential to help identify and analyse the reported use of theories in other forms of practice-oriented education research is another avenue where future research is intended.

6.3. Conclusion

In conclusion, in this paper, we have reported on the development and validation of FIETS, a tool for systematically analysing the extent to which educational theory or theory-derived frameworks are embedded in a body of literature on educational interventions. Using a case study, based on a small subset of literature from a systematic literature review on collaborative engineering design education interventions, we have illustrated that FIETS is a suitable tool for identifying (1) which educational theories are reported, and (2) the extent to which these theories inform (a) the design of an intervention and (b) the analysis of that intervention. We hope that FIETS finds use in quality assessment of theory use and provides a foundation towards more consensus of theory use and improvement of the EER field.

Acknowledgements

The authors wish to thank the SEFI community for their ongoing efforts to support PhD candidates and providing opportunities for PhDs to connect. If it was not for this community, this collaboration might not have happened. We also wish to express our gratitude to the audience during our presentation at the SEFI Annual Conference in Dublin in 2023 who provided us with valuable insights. In particular, we would like to thank Shannon Chance for her enthusiasm and encouragement.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

The data that support the findings of this study are openly available in 4TU.ResearchData at http://doi.org/10.4121/02635a70-a5c4-4616-af69-62b8b85975f5

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Appendix A. Codebook

	Code	Explanation	Example
Background	Not mentioned	Educational theory was not mentioned in the introduction and related work sections	N.A.
	Without reference	Educational theory was mentioned in the introduction and related work sections, but no reference for this theory was provided.	*‘Tecnologico de Monterrey has recently launched its Tec21 educational model that aims to develop students’ competencies by involving them in* ***active*** *and* ***collaborative learning****.’* (Lara-Prieto et al. 2020, 1)
	With reference	Educational theory was mentioned in the introduction and related work sections, and a reference for this theory was provided. No additional information that clarifies the theory is provided.	*‘Self-report measures were adapted from the psychological literature to capture students’ perceptions of engagement in the projects, including feelings of immersion or* ***flow*** *[32], [33] and social engagement in the group’s progress.’* (Nolen and Koretsky 2018, 228)
	With reference and explanation	Educational theory was mentioned in the introduction and related work sections. A reference for this theory was provided, as well as a definition, an explanation, or an example to clarify the theory.	*‘****Problem-based learning (PBL****) is a student-centred pedagogy which uses ill-structured problems in a real context to trigger the learning of fundamental concepts while developing professional skills from working in small groups (Duch, Groh, and Allen 2001; Vos and de Graaff 2004; Davidson and Major 2014).’* (Mabley, Ventura-Medina, and Anderson 2020, 330)
Intervention design	Not mentioned	Educational theory was not mentioned in method section.	N.A.
	Without explicit connection	Educational theory was mentioned in the method section, but no explicit connection was made between the theory and the design of the intervention	*‘Learning outcome of this course is that students are able to apply the principles of interaction systems in developing an application or offer an alternative interaction design. The course is delivered through the method of* ***collaborative*** *and* ***active learning*** *with a project-based approach.’* (Santoso, Sharfina, and Sadira 2018, 520)
	With explicit connection	Educational theory was mentioned in the method section, and an explicit connection was made between the theory and the design of the intervention	*‘The second lecture is in a* ***cooperative learning*** *environment where ‘Flip-J’ is one of the methods used. The Flip-J technique used in this course was executed in four stages as depicted in Figure 1. The first stage is the allocation of reading assignment. (…) The second stage is the formation of collaborative expert groups. (…) In the third stage, cooperative Jigsaw groups are formed by randomly assigning a number to each student while in their expert groups. (…) The*

(*Continued*)

Continued.

	Code	Explanation	Example
			fourth stage focuses on reflection on all the reading assignments materials.' (Akintewe, Gaines, and Small 2019, 2)
Intervention analysis	Not mentioned	Educational theory was not mentioned in the results, discussion, or conclusion sections.	N.A.
	Without explicit connection	Educational theory was mentioned in the results, discussion, or conclusion sections, but no explicit connection was made between the theory and the analysis of the intervention.	'*The affordances of the virtual laboratory allow an instructional design centered on a design outcome (in this case a process development task) where both the material and conceptual aspects of practice support students as they go about their work [18]. Such an instructional design aligns with an engineering practice emphasis in both pedagogy and student learning, similar to the 'knowledge of' described by Scardamalia and Bereiter [43] in their* ***theory of knowledge building*** *and the 'knowing' of Cook and Brown's [44]* ***bridging epistemologies***.' (Nolen and Koretsky 2018, 232)
	With explicit connection	Educational theory was mentioned in the results, discussion, or conclusion sections, and an explicit connection was made between the theory and the analysis of the intervention. No connection with practical or theoretical implications was made.	'*The results are summarised in* Table 1. *It will be noted that many of the positives are associated with* ***group-based experiential learning*** *but many of the negatives are associated with the online environment*.' (Tomkinson and Hutt 2012, 300)
	With practical implications	Educational theory was mentioned in the results, discussion, or conclusion sections, and an explicit connection was made between the theory and the analysis of the intervention. Practical implications that relate to the theory were derived.	'*The results presented here illustrate that* ***PBL*** *does offer opportunity for students to develop their collaborative problem-solving skills when dealing with real-world problems. However, the findings of this paper support the idea that students find it difficult to adapt to a PBL pedagogy, and perhaps more so, after previously learning through traditional 'lecture-based' instruction. (…)For students to become comfortable with active participation and autonomous work the implementation of PBL into an engineering curriculum might need to be more systematic and global. This approach requires a concerted effort made by whole courses/departments/faculties if the need to prepare graduates to face the global challenges are to be met through the use of active pedagogies.'* (Mabley, Ventura-Medina, and Anderson 2020, 344)
	With theoretical implications	Educational theory was mentioned in the results, discussion, or conclusion sections, and an explicit connection was made between the theory and the analysis of the intervention. Theoretical implications that lead to the advancement of the educational theory used were derived.	'*In this paper, we have proposed a number of underlying principles that pin down the essence of an* ***ecological perspective on learning*** *and learning spaces and can offer a direction for empirical, analytical and learning design efforts. (…)We showcased the merits of such an ecological approach through an example from a course in web design and development in which the learners, through a variety of practices, illuminated the emergent, expansive, interactive and synergetic approach to addressing learning tasks.'* (Damşa, Nerland, and Andreadakis 2019, 2087)[1]

[1] We did not identify an example of 'intervention analysis – with theoretical implications' in our subset of 12 papers. To still showcase an example, we added an additional study from the systematic literature review of van Helden et al. (2023), Damşa, Nerland, and Andreadakis (2019).**