European Journal of Engineering Education

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ceee20

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EUROPEAN JOURNAL OF ENGINEERING EDUCATION
https://doi.org/10.1080/03043797.2021.1903835

Developing growth mindsets in engineering students: a systematic literature review of interventions*

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ABSTRACT
Dropout from engineering studies has been linked to 'fixed mindset' beliefs of intelligence as fixed-at-birth that make students more likely to disengage when facing new challenges. In contrast, 'growth mindset' beliefs that intelligence can be improved with effort make students more likely to persist when confronting difficulties. This systematic literature review of engineering, education and psychology databases explores the effectiveness of different interventions in developing growth mindset in engineering students, what measures have been used in assessing the effectiveness of these interventions and who has benefited from these interventions, in terms of gender and year of study. We compare interventions by geographical location, intervention type, methodology for assessing mindsets, other topics studied, and effectiveness. The results show a variation in effectiveness among the fifteen included studies. The findings will be useful for educators who want to encourage growth mindset and thereby support the academic success of their students.

ARTICLE HISTORY
Received 28 January 2020
Accepted 10 March 2021

KEYWORDS
Growth mindset; beliefs; intervention; theories of intelligence; student success

Introduction

To meet stakeholder expectations, engineering educators are expected to produce graduates with a broader range of skills and attributes than in the past. The extra demands on students in a rapidly changing learning environment, increased diversity within engineering programmes, and education system weaknesses regarding diversity makes it more likely that some engineering students will encounter setbacks in their studies (Good, Rattan, and Dweck 2012; Pierrakos 2017; Jungert 2008). Beliefs about intelligence influence students' academic behaviour, particularly after a setback, such as failing an assignment. Students with fixed mindsets believe that intelligence is a fixed trait (Dweck and Leggett 1988) and may feel that they are not the 'type' for engineering if success does not come easily. Growth mindsets defend against disengagement from studies when encountering challenges because success is believed to be a result of improving intelligence and ability through applying appropriate effort (Henry et al. 2019; Stump, Husman, and Corby 2014).

There have been diverse approaches to the definition and study of intelligence. Despite these differences, intelligence, and intellectual functioning, can be defined as the ability to implement goal-directed adaptive behaviour (Sternberg 2004). The theories of intelligence are normally

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*This paper is an extended version of a contribution presented at the 2019 Annual Conference of the European Society for Engineering Education (SEFI).

organised into two groups: explicit and implicit. Explicit theories of intelligence 'are constructions of psychologists or other scientists that are based on or at least tested on data collected from people performing tasks presumed to measure psychological functioning' (Sternberg 1985, 607), and have dominated this field of study. Examples of explicit theories are: psychometric theories, which have sought to explore the (hierarchical) structure of intelligence and test mental abilities (e.g. Spearman's general intelligence, or g factor); cognitive theories, to which intelligence is composed by mental representations and mental processes that can operate on those representations; cognitive-contextual theories, which expanded cognitive theories by taking into account the multiple contexts where cognitive processes operate (e.g. Gardner's theory of multiple intelligences); and biological theories, which are based in the neuropsychological processes of intelligent behaviour.

On the other hand, implicit theories are elicited by asking people what they mean by intelligence through interaction and interpretation of their environment. These theories

> are constructions by people (whether psychologists or laypersons) that reside in the minds of these individuals (…) Discovering such theories can be useful in helping to formulate the common-cultural views that dominate thinking about a given psychological construct, whether the culture be one of people, in general, or of psychologists, in particular. (Sternberg 1985, 608)

Dweck, Chiu, and Hong (1995) developed a theoretical model of how a person's beliefs and assumptions about themselves have an impact on their judgements and behaviours. The model of Implicit Theories refers to two antagonist types of assumptions that people make about their own attributes. For example, people

> may believe that a highly valued personal attribute, such as intelligence and morality, is a fixed, nonmalleable trait like entity (*entity theory*), or they may believe that the attribute is a malleable quality that can be changed and developed (*incremental theory*). (Dweck, Chiu, and Hong 1995, 267)

According to this model, a person holding an entity theory believes that intelligence is a fixed trait that cannot be changed, no matter what strategies are used (fixed mindset); whereas a person with an incremental theory believes that intelligence is dynamic and can be changed with strategic effort (growth mindset). With this model, Dweck does not attempt to define intelligence. Instead, her research focuses on how people's theories about their intelligence, or their intellectual potential, (i.e. self-theories) can impact their behaviour – how people's beliefs can enhance, or hinder, their motivation and learning. More precisely, her research aims to understand 'the psychological mechanisms that enable some students to thrive under challenge, while others of equal ability do not' (Blackwell, Trzesniewski, and Dweck 2007, 247).

The model of Implicit Theories is particularly useful to understand human behaviour in adverse contexts. A person with a fixed mindset is 'more likely to blame their intelligence for negative outcomes'. In contrast, a person with a growth mindset is 'more likely to understand the same negative outcomes in terms of their effort or strategy' (Dweck, Chiu, and Hong 1995, 267).

To assess these implicit theories, Dweck and colleagues developed self-reported questionnaires. Mindsets are typically assessed using Dweck's Implicit Theories of Intelligence scales, with three items (Dweck, Chiu, and Hong 1995), eight items (Dweck 2000; Dweck 2006), four or six items (Dweck 2000), or adaptations of these (for example De Castella and Byrne 2015; Mindset Works Inc. 2017; Yamazaki and Kumar 2013; Karwowski 2014). Table 1 shows the different versions of the scale and corresponding items. Respondents are asked to choose their level of agreement with each statement using a 6-point Likert scale, where 1 means 'strongly agree' and 6 means 'strongly disagree'. The mindset score corresponds to an average of the items (ranging from 1 to 6), with a score of 3, or below, suggesting a stronger growth mindset, and a score of 4, or above, suggesting a fixed mindset (Dweck, Chiu, and Hong 1995).

The eight-item scale was developed to address two possible concerns: firstly, whether disagreement with fixed mindset items really does correspond with holding a growth mindset, and secondly,

Table 1. Implicit theories of intelligence scale – versions and items.

Scale	Items
3 items (Dweck, Chiu, and Hong 1995)	1. You have a certain amount of intelligence, and you really can't do much to change it. 2. Your intelligence is something about you that you can't change very much. 3. You can learn things, but you can't really change your basic intelligence.
4 items (Dweck 2000)	1. You have a certain amount of intelligence, and you really can't do much to change it. 2. Your intelligence is something about you that you can't change very much. 3. To be honest, you can't really change how intelligent you are. 4. You can learn new things, but you can't really change your basic intelligence.
6 items (Dweck 2000)	1. You have a certain amount of intelligence, and you really can't do much to change it. 2. Your intelligence is something about you that you can't change very much. 3. You can learn new things, but you can't really change your basic intelligence. 4. No matter who you are, you can change your intelligence a lot. (*) 5. You can always greatly change how intelligent you are. (*) 6. No matter how much intelligence you have, you can always change it quite a bit. (*)
8 items (Dweck 2000; Dweck 2006)	1. You have a certain amount of intelligence, and you really can't do much to change it. 2. Your intelligence is something about you that you can't change very much. 3. No matter who you are, you can significantly change your intelligence level. (*) 4. To be honest, you can't really change how intelligent you are. 5. You can always substantially change how intelligent you are. (*) 6. You can learn new things, but you can't really change your basic intelligence. 7. No matter how much intelligence you have, you can always change it quite a bit. (*) 8. You can change even your basic intelligence level considerably. (*)
8 items (Mindset Works Inc. 2017)	1. No matter how much intelligence you have, you can always change it a good deal. (*) 2. You can learn new things, but you can't really change your basic level of intelligence. 3. I like my work best when it makes me think hard. (*) 4. I like my work best when I can do it really well without too much trouble. 5. I like work that I'll learn from even if I make a lot of mistakes. (*) 6. I like my work best when I can do it perfectly without any mistakes. 7. When something is hard, it just makes me want to work more on it, not less. (*) 8. To tell the truth, when I work hard, it makes me feel as though I'm not very smart.
8 items (De Castella and Byrne 2015)	1. I don't think I personally can do much to increase my intelligence. 2. My intelligence is something about me that I personally can't change very much. 3. To be honest, I don't think I can really change how intelligent I am. 4. I can learn new things, but I don't have the ability to change my basic intelligence. 5. With enough time and effort I think I could significantly improve my intelligence level. (*) 6. I believe I can always substantially improve on my intelligence. (*) 7. Regardless of my current intelligence level, I think I have the capacity to change it quite a bit. (*) 8. I believe I have the ability to change my basic intelligence level considerable over time. (*)
9 items (Yamazaki and Kumar 2013)	1. Intelligence is largely inherited or fixed by birth. 2. The development of intelligence is largely a matter of opportunities and experiences one has in childhood. 3. I believe bell curve shape is an accurate depiction of intelligence. 4. There are only a few highly intelligent people in any population. 5. Hard work can only go so far; one must be intelligent to really succeed in life. 6. As people grow older, their level of intelligence becomes lower. 7. Only those who are intelligent can succeed at school. 8. Some people simply do not have the intelligence to succeed in college. 9. Intelligence can develop all through life. (*)

Note: Items marked with (*) need reverse scoring.

that including only fixed mindset items may encourage 'universal endorsement' by participants rather than assessing their beliefs. Two validation studies described in Levy, Stroessner, and Dweck (1998) found that disagreement with fixed mindset items did represent agreement with growth mindset items, and that the three-item and eight-item scales had high correlation (0.83 and 0.92 in two studies). Dweck (2000) supported the use of the six-item scale for children and the eight-item scale with adults. Hong et al. (1999, 590) argue that the three-item mindset scale has high internal validity and avoids the problem that 'continued repetition of the same idea becomes somewhat bizarre and tedious to the respondents'.

Psychosocial support in higher education can improve gender and race equality in STEM disciplines (Casad et al. 2018; Fong et al. 2017). Developing growth mindsets is valuable for engineering education because, compared to fixed mindset students, growth mindset students are more likely to adapt and succeed in demanding or stressful situations (Costa and Faria 2018), to have favourable views on the benefits of group work (Alpay and Ireson 2006), to set learning goals rather than focusing on grades (Robins and Pals 2002), to have greater well-being (Ortiz Alvarado, Rodríguez Ontiveros, and Ayala Gaytán 2019), and to support policies aimed at redressing social inequality (Rattan et al. 2012). When mistakes are viewed as learning opportunities instead of judgements about fixed traits, students are more willing to participate and demonstrate the perseverance and resilience needed for creativity and innovation (Dweck 2006). Growth mindsets may also help with retention of engineering students. For example, Heyman, Martyna, and Bhatia (2002) found that all of the female students who dropped a course after encountering academic difficulties had fixed mindsets.

Growth mindset interventions can buffer students from a drop in grades during transition, such as moving to high school (Blackwell, Trzesniewski, and Dweck 2007; Yeager, Schneider, et al. 2016) and starting university (Yeager, Walton, et al. 2016). The experience of struggling and then succeeding at university may explain a modest development of growth mindsets in first-year engineering students even without any intervention by Campbell (2019), although other studies found that engineering students developed fixed mindsets in their first year (Reid and Ferguson 2014) or subsequent years (Flanigan et al. 2015).

Following Carol Dweck's popular book on mindsets (Dweck 2006) and TED Talk (Dweck 2014), there was an increase in growth mindset correlation studies (e.g. Bostwick et al. 2019) and growth mindset intervention studies (e.g. Paunesku et al. 2015), mostly in school contexts. Research on post-school growth mindset interventions seemed to include few interventions involving university students studying engineering. In addition, a meta-analysis by Sisk et al. (2018) found that growth mindsets did not consistently correlate with higher grades and that context may explain why some intervention studies gave unexpected mixed results (Yeager and Walton 2011). As more engineering educators take tentative steps to include psychosocial support in their teaching, a systematic review of growth mindset interventions that have already been applied to engineering students will allow educators to make informed decisions when designing their own growth mindset interventions and choosing how to assess the effects of interventions. As suggested by Borrego, Foster, and Froyd (2014), this systematic review compiles and synthesises relevant interdisciplinary studies, and informs engineering education practice. Ultimately, it can guide and accelerate the application of effective growth mindset interventions with engineering students. This systematic literature review addresses the research questions:

(1) How effective are different interventions to develop growth mindset in engineering students?
(2) What measures have been used in assessing the effectiveness of these interventions?
(3) Who benefited from these interventions, in terms of gender and year of study?

The answers to these questions will help engineering educators plan growth mindsets interventions based on previous scholarship that involved engineering students.

Method

We followed the procedures for a systematic literature review involving engineering education research outlined in Borrego, Foster, and Froyd (2014). This involved:

- Defining the inclusion criteria.
- Finding and cataloguing sources.
- Assessing the quality of each identified study.
- Synthesising the included results.

Defining the inclusion criteria

Search terms were created to find studies that met the following conditions:

(1) The interpretation of 'growth mindset' aligned with Dweck's theory of mindsets.
(2) The intervention involved engineering students in tertiary studies (college or university).
(3) The research design involved an intervention aimed at developing growth mindsets.

The exact search terms used are presented in Table 2.

Where a database allowed, a suffix of * was used for multiple endings, e.g. compar* for compare and comparison. Some databases, e.g. Engineering Village, did not allow the use of * inside quotation marks. Where the search string was too long for the database (e.g. JSTOR), multiple searches were made to eliminate phrases that did not produce more results. Two subject librarians validated the iterative development of the search string and confirmed that it met the inclusion and exclusion criteria. The inclusion and exclusion criteria, with rationales, are presented in Table 3.

Finding and cataloguing sources

A comprehensive literature search for journal articles, conference papers, books, book chapters and doctoral dissertations was carried out before and on 1 January 2020. Databases on education,

Table 2. Search terms used in databases.

('growth mindset' OR 'growth mindsets' OR 'fixed mindset' OR 'fixed mindsets' OR 'incremental mindset' OR 'incremental mindsets' OR 'malleable intelligence' OR 'implicit theories of intelligence')	AND ('engineering student' OR 'engineering students' OR 'engineering class' OR 'engineering classes' OR 'engineering classrooms' OR 'incoming first-year students')	AND (intervention OR interventions OR experiment OR experiments OR measure OR measurement OR compare OR comparison)

Table 3. Inclusion and exclusion criteria for mindset intervention studies.

Category	Inclusion criteria	Exclusion criteria	Rationale
Publication type	Peer-reviewed journal articles, conference papers, books, book chapters and doctoral dissertations.	Not peer-reviewed.	Quality assurance of the research; more credible results.
Publication language	Publications in any language found from database searches using English search terms.	Article not able to be translated into English, or translation quality weak.	The number of translations required were small; including more studies increases the value of the review.
Participants	Engineering students and students sharing classes with engineering students.	Not involving engineering students as the group targeted for the intervention.	The research questions target engineering students in post-school settings.
Purpose of intervention	The intervention aims to develop growth mindsets, or changes in mindset are reported.	The intervention does not aim to develop growth mindsets, or there is no assessment of students' mindsets.	The research questions focus on developing growth mindsets.
Theory used	Dweck's (1986, 2008) theory of growth/incremental and fixed/entity mindsets.	A use of the term 'mindset' different from Dweck's theory.	The research questions focus on Dweck's theory of mindsets.
Outcome measures	An assessment of the effectiveness of the intervention is made.	No assessment of the intervention is made.	The research questions ask for measures for assessing the effectiveness of the intervention.
Date	Published before 1 January 2020 and after 31 December 1982.	Published after 1 January 2020 and before 1 January 1983.	A final check for new results was made on 1 January 2020. Dweck's work on growth mindsets was not available before 1983.

Table 4. Number of duplicated, included and excluded records.

Database	Total records	Duplicates	Excluded	Included
Academic Search Premier	2	1	1	0
Education Database	87	19	67	1
Engineering Village	13	9	2	2
ERIC	3	2	0	1
JSTOR	3	2	1	0
Proquest Dissertations and Theses	373	40	327	6
PsycARTICLES	1	0	1	0
PsycINFO	2	2	0	0
ScienceDirect	7	0	7	0
Scopus	126	18	104	4
Web of Science	4	3	0	1
Wiley Online Library	21	5	16	0
Total	642	101	526	15

engineering and psychology listed in Borrego, Foster, and Froyd (2014) and others available through our institutional libraries were searched.

A total of 642 records were returned from the 12 databases listed in Table 4. From these, 101 duplicate records were removed. A spreadsheet with details (author, title, date published, abstract, type of resource, journal/conference/university name, database, reason for exclusion) for the remaining 541 records was compiled by the first author with advice and some additions made by the second author and verifications by the third author. A total of 520 records were excluded after scanning abstracts or full texts for evidence of a growth mindset intervention involving engineering students. The remaining 21 records that seemed to meet inclusion criteria were analysed in the spreadsheet using a further 10 headings: *location of study, purpose/objectives of study, research questions, students targeted* (year of study, demographics, course), *details of intervention* (duration, incentives, facilitator training), *alternatives to intervention* (e.g. no intervention, control group with similar activity), *outcome measures* (scales, interviews, course results), *findings, quantitative/qualitative/mixed design,* and *measures of treatment effect*.

Exclusion reasons for the 526 excluded records were: no growth mindset intervention and/or not involving engineering students ($n = 517$), not one of the included research formats (i.e. journal article, conference paper, book, book chapter or doctoral dissertation, $n = 6$), no assessment of the effectiveness of the intervention ($n = 2$) and not being able to include on the basis of the abstract or acquire the full text ($n = 1$).

Six records were excluded after a full analysis, leaving 15 included results. The 15 included records came from 2 out of 132 journal articles, 6 out of 59 conference papers, and 7 out of 426 doctoral dissertations. No records were included from books and book chapters.

The flow diagram in Figure 1 represents the literature review process and number of records at each stage.

Synthesising the included results

The included studies were compared in terms of types of intervention; methodologies used; other topics addressed in the studies in addition to mindsets, effectiveness of interventions, and who benefited (in terms of gender and year of study). The results are summarised in the table in the Appendix under headings *research design* (including qualitative/quantitative/mixed methods, variables, duration of intervention, population), *details of intervention*, and *findings*. In the Appendix, the fifteen included studies are presented by alphabetical order listing the first author, and each study is associated with a number. This number is used to identify each study in Tables 5–8 to facilitate comparison and data cross checking.

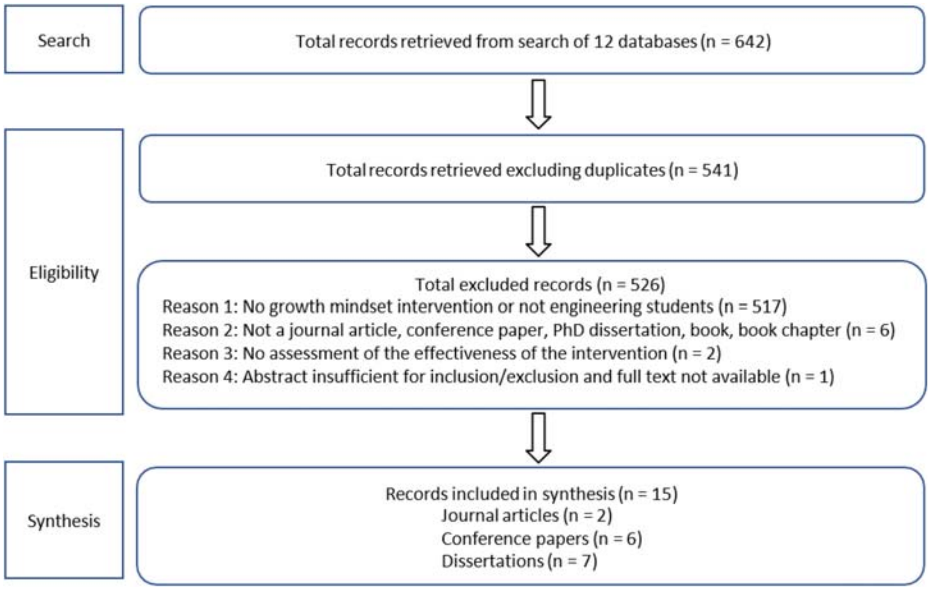

Figure 1. Flow diagram for the selection and analysis of included literature.

Table 5. Mindset assessment tool details.

Study number	Items in scale	Likert options	Item modification	Reference for mindset scale
11	3	5	Original	PERTS (2015)
1	3	6	Original	Hong et al. (1999)
2	3	6	Original	Dweck (2000); Hong et al. (1999)
7	3	6	Original	Hong, Chiu, and Dweck (1995)
14	3	6	Original	Dweck (2000)
9	3	7	Modified: Maths	Dweck (2000)
6	4	7	Original	Dweck (2000)
15	8	5	Original	Dweck (2006)
3	8	6	Original	Dweck (2006)
12	8	6	Original	Dweck (2000)
13	8	6	Modified: Writing	Palmquist and Young (1992); Dweck (2000); Limpo and Alves (2014)
8	16	7	Modified: Music, Maths	Dweck (2000)
10	27	Unspecified	Unspecified	'Authored by Dweck'
5	No scale	No scale	n/a	For discussion prompts: Dweck (2006)
4	Unspecified	Unspecified	Unspecified	'Dweck's general mindset measure'

Results

Geographic distribution of studies[1]

The vast majority of included studies were based in the United States of America, including all seven PhD dissertations. The two oldest included studies [#4, 14] involved universities and authors from the United Kingdom.

A possible limitation of this review was that restricting the search terms to English may have limited the number of eligible studies. Only one result was in a language other than English (Arabic), and after assessing the translated abstract, using Google Translate, the article was excluded. Results may have been missed due to our unfamiliarity of mindset terms specific to other cultures.

Table 6. Study conclusions, reasons for conclusions, initial and final mindset scores as percentages of scales.

Study number	Study conclusion	Reason for study conclusion	Initial mindset scores (0% = fixed mindset, 100% = growth mindset)	Final mindset scores (0% = fixed mindset, 100% = growth mindset)
3	Effective	Large matched-pair correlations (growth mindset $r = .90$ and fixed mindset $r = -.80$); large effect sizes (0.54 growth, 0.48 fixed).	55.0%	77.0%
4	Effective	Sig. difference in mindset score changes between intervention and control groups ($p < 0.044$).	52.4% (control) 54.2% (intervention)	47.8% (control) 58.6% (intervention)
7	Effective	Sig. higher mindset score for intervention vs. control or comparison groups ($p < 0.001$).	No pre-test	64.0% (control) 63.8% (comparison) 75.0% (intervention)
9	Effective	Sig. higher post-intervention mindset score for mindset intervention group vs. control ($p = 0.035$).	68.5% (control) 65.5% (mindset intervention)	63.5% (control) 68.8% (mindset intervention)
13	Effective	Intervention group 'improved their mindsets more significantly than students in the control and comparison groups."	Not given (full text not available)	Not given
1	Inconclusive	Mixed results for different groups. Sig. change in GPA for Latina/o students ($p < 0.002$).	75.4% (control) 74.8% (intervention)	No values given
5	Inconclusive	No assessment of a change in mindset. Insufficient data.	n/a	n/a
8	Inconclusive	Insufficient details. Sig. not calculated, graph suggests a sig. change in mindset; mixed qualitative responses.	No values given	No values given
10	Inconclusive	Insufficient details. Intervention seems to reduce trend towards fixed mindsets over 1st year.	48.4% (control) 37.4% (intervention)	46.6% (control) 37.6% (intervention)
14	Inconclusive	Sig. changes in mindset scores for some survey items but in different directions ($p = 0.033$, 0.004 and 0.011 respectively for listed mindset changes).	For two fixed mindset items: 55.2% (control) 51.4% (intervention B) 66.5% (intervention C)	For two fixed mindset items: 50.6%% (control) 65.8% (intervention B) 45.6% (intervention C)
2	Not effective	No sig. effects on mindset scores. Math test scores decreased.	75.8% (intervention group 1) 76.6% (intervention group 2)	72.0% (intervention group 1) 83.8% (intervention group 2)
6	Not effective	No sig. effects of interventions on mindset assessment.	70.3% (in-class intervention, n=66) 69.5% (reading group, n=6)	73.3% (in-class intervention) 75.0% (reading group)
11	Not effective	No sig. effect of intervention on academic performance, units completed or retention.	62.5% (average)	No values given
12	Not effective	No sig. difference in mindset scores between intervention and control groups.	58.5% (average)	No values given
15	Not effective	No sig. difference in mindset scores between intervention and control groups.	76.4% (control) 70.2% (intervention)	76.9% (control) 70.5% (intervention)

Types of interventions

The dominant intervention, seen in ten of the studies, was sharing mindset ideas with students through readings [#1, 5, 6, 8, 11], videos [#8, 12], lectures [#4, 6, 14], or online tutorials [#7, 9], followed by discussion or reflective writing, including students writing advice for other students. One of those studies [#4] also used two other interventions: a 'crib sheet' of alternative strategies when a computer programme fails (to counter the fixed mindset approach of re-trying the same strategy or giving up when stuck), and feedback on assignments stating that students who put in

Table 7. Types of interventions and effect sizes in mindset intervention studies.

Study number	Study conclusion	Type of intervention	Effect size
3	Effective	Introductory course *Engineering the Mind* aimed to develop growth mindset	Large, matched-pairs rank-biserial correlations were $r=0.90$ and −0.80 for growth and fixed mindset. Large effect sizes were calculated for growth and fixed mindset: 0.54 and 0.48, respectively.
4	Effective	Sharing mindset ideas through lectures; discussion/reflective writing	Significant difference between intervention and control groups ($F(1,75)=4.18$; $p<.044$).
7	Effective	Sharing mindset ideas through online tutorials; discussion/reflective writing	Post-test, treatment group mean mindset scores (4.75) were significantly higher ($p<0.001$) than the mean mindset scores of both comparison (4.19) and control groups (4.20), where scores range from 1 to 6. Average GPAs in treatment group (3.10) were significantly higher than the control group (2.86) but not the comparison group (3.03).
9	Effective	Sharing mindset ideas through online tutorials; discussion/reflective writing	Even after controlling for demographics, course sections, pre-survey scores, and test 1 scores, the growth mindset group ($b=.235$, $SE=.097$, $p=.035$, $d=.235$) had significantly higher post-survey intelligence beliefs than the control group.
13	Effective	Interaction with an embedded writing tutor in an engineering course	Data from 36 students who completed pre- and post-intervention surveys showed that students who received the embedded tutoring intervention improved their mindsets more significantly than students in the control and comparison groups. (Values not available.) Students' final drafts were also substantially better in terms of organisation, style, and mechanics.
1	Inconclusive	Sharing mindset ideas through readings; discussion/reflective writing	Mixed results for different groups. Latino/a students who received the growth mindset intervention had significantly higher first-semester GPAs (3.13 vs 2.73 on a scale of 0–4, $p<0.01$), 2nd semester GPAs (2.97 vs. 2.64, $p<0.02$) and 1st year cumulative GPAs (3.05 vs. 2.69, $p<0.002$) than their peers in the control group.
5	Inconclusive	Sharing mindset ideas through readings; discussion/reflective writing	No quantitative data. Students reconsidered past interpretations of experiences and projected forward on possible changes towards a growth mindset. Students understood that growth mindset 'was not an all or nothing switch to be flipped'.
8	Inconclusive	Sharing mindset ideas through readings and videos; discussion/reflective writing	50% of students shifted to a stronger growth mindset post-intervention. No effect size given.
10	Inconclusive	Open-ended projects	No significant increase in growth mindsets. Intervention group shifted less towards fixed mindsets compared to control and previous year groups.
14	Inconclusive	Sharing mindset ideas through lectures; discussion/reflective writing	Some statistically significant changes but not all in the same direction. For the two fixed mindset items pre- to post-intervention mean scores (on a 1–6 scale) were 3.57–4.29 ($p=.033$, intervention B), 3.66–3.28 ($p=.004$, intervention C) and 3.76–3.53 ($p=.011$, control).
2	Not effective	Mindset-endorsing mathematics word problems	No significant changes in mindset beliefs. Students' performance on a 30-item challenge activity and 10-item mathematics quiz decreased between pre-test and a post-test three weeks later.
6	Not effective	Sharing mindset ideas through readings and lectures; discussion/reflective writing	The change towards growth mindsets on pre- and post-surveys showed no statistically significant difference.
11	Not effective	Sharing mindset ideas through readings; discussion/reflective writing	After 2 years there was no effect of either the growth mindset or the belonging intervention on academic performance, units completed, or retention.

(*Continued*)

Table 7. Continued.

Study number	Study conclusion	Type of intervention	Effect size
12	Not effective	Sharing mindset ideas through videos; discussion/reflective writing	No significant difference in mindset between the mindset intervention and control conditions (Wilks' λ (386, 2) = .99, p = .12, partial η^2 = .011).
15	Not effective	Introductory course *On Course* aimed to develop growth mindset	No significant difference between mindset means for the pre-test (intervention mean = 60.95, sd = 10.02, n = 85; control mean = 64.88, sd = 8.31, n = 18) and post-test (intervention mean = 61.09, sd = 10.46, n = 61; control mean = 65.23, sd = 11.26, n = 13) on a scale from 16 to 80. Black first-generation learners had a significantly higher mean difference in pre- and post-test scores (7.1) than white first-generation learners (ρ = .034).

Table 8. Mindset intervention conclusions, study size, participants' year of study and percentage female participants.

Study number	Study conclusion	Number of students	Study size	Participants year of study	Female participants
3	Effective	15	Small	1 (27%), 2 (20%), 3 (60%), 5, 6 (7%)	20%
4	Effective	89	Medium	1	Unknown
7	Effective	489	Large	1	61%
9	Effective	426	Large	1 (83%), 2 (11%), 3 (5%)	79%
13	Effective	57	Medium	unknown	Unknown
1	Inconclusive	7686	Large	1	50%
5	Inconclusive	8	Small	1	Unknown
8	Inconclusive	26	Small	3	23%
10	Inconclusive	84	Medium	1	Unknown
14	Inconclusive	228	Large	1 (mostly)	Unknown
2	Not effective	73	Medium	unknown	Unknown
6	Not effective	66	Medium	1	Unknown
11	Not effective	441	Large	1	16%
12	Not effective	1021	Large	1 (75%)	25%
15	Not effective	177	Large	1	Unknown

time and effort usually succeed. Growth mindset messages were included in mathematics word problems in study #2. Two studies involved introductory courses designed to increase growth mindsets [#3, 15]. One study [#10] used open-ended projects as a means of encouraging growth mindsets by valuing alternative strategies rather than a single correct answer. The remaining study [#13] involved the use of a course-embedded writing tutor to influence students' mindsets.

Methodologies to assess mindsets

The dominant methodology was quantitative (nine studies) or mixed methods (five studies). Different versions of mindset scales were used to classify students on the spectrum of fixed to growth mindsets, as detailed in Table 5.

Of the fourteen studies that included quantitative data, nine studies [#1, 2, 3, 6, 7, 11, 12, 14, 15] used original mindset scales, three [#8, 9, 13] used modified items, for example, 'Music talent can be learned by anyone,' [#8]; 'You can learn new things, but you can't really change your math intelligence,' [#9]; and 'Good writers are born, not made,' [#13], and two studies did not mention the type of scale items used. Six studies used three-item scales [#1, 2, 7, 9, 11, 14] and four used eight-item scales [#3, 12, 13, 15]. Other versions used four items [#6], sixteen items [#8] and 27 items [#11]. One study [#13] asked an additional three mindset-focussed questions on talent versus effort, two of which were open-ended.

Qualitative data probed students' reactions to mindset theory and their ability to learn. Collecting qualitative data involved longer and more personal engagements with mindset concepts for students compared with purely quantitative studies, through interactions with the researchers in interviews, focus group discussions and written responses to questions. The single study that involved only qualitative methods used thematic analysis of students' written responses to reading group discussions of Dweck's (2006) book *Mindset: The new psychology of success* [#5].

The table 'Summary of included studies' in the Appendix summarises the research design, interventions and findings of the 15 included studies.

Effectiveness of interventions

The following definitions were used to categorise studies as effective, inconclusive or not effective: Effective:

- Statistically significant ($p < 0.05$) change in mindset score from pre- to post-intervention survey OR
- Statistically significant ($p < 0.05$) difference in post-intervention mindset score between intervention and control groups when there was no pre-intervention mindset score OR
- Large ($|r|>=0.7$) matched-pairs correlations for pre- and post-intervention mindset scores OR
- Qualitative data supporting the authors' conclusion that intervention was effective.

Inconclusive:

- Insufficient details to categorise study as effective or not effective OR
- Weak ($0.3<|r|<0.7$) matched-pairs correlations for pre- and post-intervention mindset scores OR
- Mixed results for different groups within a study OR
- No data (work-in-progress study).

Not effective:

- No statistically significant change in mindset score from pre- to post-intervention survey OR
- No statistically significant difference in post-intervention mindset score between intervention and control groups when there was no pre-intervention mindset score OR
- No ($|r|<0.3$) matched-pairs correlations for pre- and post-intervention mindset scores OR
- Qualitative data supporting the author's conclusion that intervention was not effective.

Table 6 shows the study conclusions, reasons for conclusions, initial mindset scores and final mindset scores. To enable comparisons over scales with different number of Likert options, mindset scores were converted to percentages. Firstly, scales where higher values indicated fixed mindsets were reversed, for example, a score of 5 on a scale from 1 to 6 where higher values indicate fixed mindsets would be converted to 2 on a scale from 1 to 6 where higher values indicate growth mindsets. Secondly, mindset scores were converted to percentages using the formula

$$\text{Mindset score\%} = (\text{mindset score} - \text{lowest value on scale}) / (\text{highest value on scale} - \text{lowest value on scale}).$$

For example, on a scale of 1–6, a score of 3.5 would be 50%, a score of 3 would be 40% and a score of 6 would be 100%.

Five studies [#3, 4, 7, 11, 13] reported that the mindset interventions were effective. Small, statistically significant difference in mindset score changes between intervention and control groups were found in two studies [#4, #9]. Study #7 did not use pre-intervention mindset assessment but found significantly higher post-intervention mindset scores for the intervention group compared to control or comparison groups. While values were not available to assess the extent of growth mindset development in study #13, statistically significantly higher changes in mindset score were reported for the intervention group compared to control or comparison groups. Only one study, [#3], reported large effect sizes for the mindset intervention.

Five studies [#1, 5, 8, 10, 14] were inconclusive regarding the effect of the intervention on developing growth mindsets. Study #1 showed mixed results for different groups. Study #5 did not provide sufficient details from which a change in mindsets could be determined. Studies #8 and #10 did not provide sufficient details for classification as effective or not effective. In addition, study #8 had mixed qualitative responses and study #10 showed that although mindset scores did not move towards growth mindsets, the intervention offset a trend towards fixed mindsets that was observed in a previous year. Mixed results across intervention groups were reported in study #14.

Five studies [#2, 6, 11, 12, 15] reported that the mindset interventions were not effective. Studies #2, 6, 12 and 15 found no significant change in mindset as a result of the intervention. In addition, study #12 found no significant effect on motivation, engineering identity, course grades, GPA and retention. Study #11 found no significant effect on academic performance, units completed or retention.

The effectiveness of interventions was quite evenly distributed among study sizes. Effective studies comprised 1 of the 3 small studies, 2 of the 5 medium studies and 2 of the 7 large studies. 'Not effective' studies comprised 2 of the 5 medium studies and 3 of the 7 large studies. Inconclusive studies comprised 2 of the 3 small studies, 1 of the 5 medium studies and 2 of the 7 large studies.

The effectiveness of interventions was also quite evenly distributed among the types of interventions, as shown in Table 7. Three types of interventions were used exclusively in effective interventions: an introductory course *Engineering the Mind* aimed at developing growth mindsets [#3]; sharing mindset ideas through online tutorials followed by discussion/reflective writing [#4, 7, 9]; and interaction with an embedded writing tutor in an engineering course [#13].

Who benefited?

Overall, the included studies focussed on first-year students. Only two studies [#3, 8] were not directed at first year students. Both were small studies (15 and 26 students) with 20–23% female participants. Study #3 reported the greatest changes in mindset scores while study #8 was inconclusive.

Only seven of the studies reported the percentage of female participants. Two of the effective studies [#7, 9] stood out for having very high female participation (61% and 79%) as well as being large studies ($n = 489$ and $n = 426$). Two of the five studies that were not effective [#11, 12] reported much lower female participation (16% and 25% female) and were also large studies ($n = 441$ and $n = 1021$). The largest study, [#1] had 50% female participants but was inconclusive. Table 8 summarises the study conclusions, study sizes, study year of participants and percentage of female participants.

Discussion and conclusion

The results suggest that growth mindsets can be developed in engineering students and that some types of interventions are more effective than others. Within the five studies that had effective interventions, two studies involved repeated interaction with course instructors: study #13, involving interactions with an embedded writing tutor in an engineering course, and study #3, which used the course *Engineering the Mind* to teach topics closely aligned with mindset theory such as neuroplasticity and goal orientation theory. In contrast, the course *On Course* used in the multi-campus, large study #15 had a focus on whole-person learning, including self-efficacy, self-responsibility, and emotional intelligence and was ineffective in developing growth mindsets. The alignment of course instructors to Dweck's (2006) interpretation of 'growth mindset' may have impacted the effectiveness of instructor-focussed studies and this is suggested as a topic for future research.

A number of interventions first introduced students to growth mindsets (through lectures, readings, online tutorials or videos) and then asked students to complete a discussion or writing task. Of these, interventions using online tutorials [#7, 9] were the most effective, followed by interventions using lectures [#4, 14]. Interestingly, none of the interventions that introduced growth mindsets through readings [# 1, 5, 6, 8, 11] were effective. Further research may help to explain why online tutorials appear to be more effective than reading, and how this design feature may contribute to the effectiveness of a mindset intervention.

Regarding interventions with low-effect results, we offer four reasons that should be considered by researchers and educators interested in developing and implementing growth mindset interventions. Firstly, engineering students may already start with growth mindsets, as was the case in study #8. Secondly, there may be a trend for engineering students to develop a fixed mindset in their first year, as observed in study #10, particularly in students taking computer science. Interventions may be off-setting the trend towards stronger fixed mindsets. Thirdly, as noted in study #13, students may exhibit growth mindset and fixed mindset traits simultaneously, making it difficult to assess changes in mindsets. Fourthly, beside the follow-up of study #11 that looked at results two years after the intervention, none of the included studies investigated the long-term effects of the growth mindset interventions. We recommend longitudinal studies on growth mindset interventions to track possible benefits that may be missed in shorter studies. Shifting beliefs is often a slow process and most of the included studies reported on results gathered over a semester or a year. Follow-up studies with qualitative data may show that growth mindset interventions are effective over longer time spans.

The application of educational and positive psychology in engineering education for over two decades (e.g. Baillie and Fitzgerald 2000; Alpay and Ireson 2006; Sheu et al. 2018; Direito, Chance, and Malik 2019) reflects the growing awareness of how psychological factors affect how engineering students think, feel and act (e.g. Rohde et al. 2019; Yadav, Alexander, and Mehta 2019). Nine of the fifteen growth mindset studies in this review involved other psychology theories and constructs, namely sense of belonging [#1, 11, 12], self-efficacy [#4, 7, 9, 10, 11, 12], grit and persistence [#3, 7], task value [#9, 12], goal setting [#12], affectivity [#4, 10], stereotype disbelief [#7], whole-person learning [#15], perceived competence [#12] and engineering identity [#12]. The trend of researching mindsets along with other topics reflects the interconnectedness of psychology topics in engineering education and research.

Beliefs and behaviours that influence learning are interrelated, multifaceted, sometimes contradictory and can surface under circumstances that may be particular to an individual, which complicates the study of their influence in learning. We support the calls for further research on implementing and assessing multi-topic interventions (Bazelais et al. 2018; Fong et al. 2017) and suggest that engineering education research and practice would be strengthened by expanding the focus of studies that involve beliefs and behaviours to include influences other than individual psychological factors, such as cultural and organisational context (Briody et al. 2019). For example, exploring how organisational mindsets (Canning et al. 2020) can be promoted through collaborative peer-to-peer interactions (Briody et al. 2018), and how students' individual beliefs can affect or be impacted by their team's goals, motivation and behaviour (Murphy and Dweck 2010). We can then expect that a growth mindset intervention may have different outcomes in a competitive culture where top achievers are rewarded above others versus a co-operative culture where grading is pass/fail. The narrow focus on beliefs from a psychology perspective may be one of the reasons why the growth mindset interventions with engineering students did not produce big changes towards growth mindsets.

In addition, since fixed mindsets may be inadvertently encouraged regardless of teaching approaches (Campbell, Craig, and Collier-Reed 2020), the effectiveness of growth mindset interventions may be negated by contexts that send fixed mindset messages. The influence of the context in which an intervention is implemented may be a reason for the unexpected results reported in Sisk et al. (2018) and in some of the studies in this review, such as [#10]. The six studies that used qualitative data included the smallest five studies, [#3, 5, 6, 8, and 13]. We speculate that the more personalised nature of qualitative data collection compared with answering surveys may contribute to buy-in from participants to participate more fully in the interventions, and therefore raise the quality of the intervention. We also speculate that the quality of the intervention may vary according to the mindset of those implementing the intervention and those who have a strong influence on the students' learning experience – lecturers, tutors and peers. Further research that can provide a measure of the quality of an intervention, possibly through the inclusion of qualitative data, is recommended.

Most studies used quantitative mindset assessment tools (Dweck's scales), as expected. Comparing the various scales used to assess mindset, the three-item scale has the advantages of high reliability without the extra work required by use of the eight-item scale. Considering that the original scales were validated with a previous generation of students (Dweck, Chiu, and Hong 1995), mindset studies would benefit from validation studies across different countries, contexts and language translations.

Quantitative data, as collected by the vast majority of the studies reviewed in this paper, allow for easy comparisons against standardised criteria from which deductions can be made. However, quantitative studies offer limited insight on unanticipated results, such as when growth mindset interventions are not effective or inconclusive. Qualitative data can provide 'fascinating and useful insights into student thinking' (Simon et al. 2008, 181) that may reveal blind-spots, misinterpretations of data collection instruments, reasons why interventions are, or are not, successful, and directions for future research. For example, while the mixed method study [#6] was assessed as not effective, the qualitative data showed that 'students had significant misconceptions about mindset theory including contradictory ideas involving effort and intelligence' (Dringenberg and Kramer 2019, 1061). The misconceptions revealed in the qualitative data in study [#6] help to explain why the mindset scale scores did not improve after the intervention. The two effective, mixed methods studies [#3,13], point to mindset interventions that involve students' reflection and interaction with lecturers who are committed to develop growth mindsets as a promising avenue for future mindset interventions.

Interventions that increase growth mindsets have been shown to be most beneficial for students from lower socio-economic backgrounds and minority students (Claro, Paunesku, and Dweck 2016; Sisk et al. 2018). If the trend of increasing diversity in engineering courses (Einaudi 2011) continues, increased positive effects from growth mindset interventions may be realised. Finding subtle ways to target interventions at students who might benefit the most from them, for example, students with lower school GPAs and lower baseline mindset beliefs (Broda et al. 2018) is suggested for future studies. Not all of the included studies included demographic data to test whether interventions were more effective for sub-groups, which limited our assessment of the effectiveness of mindset interventions for different demographic groups. However, it is noteworthy that two large studies [#7, 9] with high female participation were effective. Future studies could explore whether interventions are more effective for female students and if growth mindset environments could help to attract and retain female engineering students.

The small number of effective studies makes it difficult to generalise advice on what mindset interventions should be used or avoided. Nevertheless, based on our analyses, the following recommendations can guide and help engineering educators develop growth mindsets in engineering students:

- Introduce mindsets through online tutorials or lectures rather than readings.
- Create opportunities to discuss and reflect on the importance of growth mindsets for learning.
- Make students feel that their written reflections will be of value to others, either as advice for future students, or as part of graded coursework.

This systematic literature review of growth mindset interventions for engineering students points to a research field that is still developing. Further research – including longitudinal studies, qualitative data and exploring learning in different contexts – can help us to understand the complexities of how to develop and assess growth mindsets in engineering students, particularly for engineering classes with a high level of diversity among students. The variation in effectiveness of these studies supports the idea that mindset interventions should be part of multi-focus strategies to support student success. The range of interventions used in the reported studies provides inspiration for new interventions to incorporate as part of a broader strategy to improve the success of engineering students.

Note

1. After analysis, record [#11] was discovered to be a work-in-progress paper. The database search did not return any follow-up papers, but an internet search found a follow-up paper, which was included in the summary table in the Appendix. For this reason, records are now referred to as studies.

Acknowledgements

This research is supported by the National Research Foundation (NRF) in South Africa and the Research Office at the University of Cape Town. Opinions expressed, and conclusions arrived at, are those of the authors and are not necessarily to be attributed to the NRF.

Disclosure statement

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

Funding

This research is supported by the National Research Foundation (NRF) in South Africa and the Research Office at the University of Cape Town.

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Note: Asterisks Indicate References Included as Part of the Systematic Literature Review.

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Appendix. Summary of included studies

#	Study	Research design	Details of intervention	Findings
#1	Broda et al. (2018) Reducing inequality in academic success for incoming college students: A randomised trial of growth mindset and belonging interventions. *(Journal article)*	Quantitative. Randomised control study. Pre-intervention survey taken before or during 2-day orientation program, post-intervention survey after 2 semesters. 3-item, 6-point Likert mindset scale and 4-item, 5-point Likert belonging uncertainty scale. Post-intervention variables: differences in grade point averages, course credits attempted, course credits completed, full-time enrolment. Control variables: ACT score, high school grade point average (GPA), Pell grant eligibility, and first-generation status. Participants: 7686 students, representing more than 90% of incoming first-year students at a large USA Midwestern public university, Michigan State University. 50.3% females, 49.7% males. For growth mindset intervention, students were white ($n = 3416$), African American ($n = 318$), Latino/a ($n = 193$), and other (Asian / Multiracial / unspecified, $n = 430$). International students (about 15%) were excluded from analysis.	Reading, reflective writing, and writing advice for new students. Online, students read a short scientific article explaining that the brain, like muscles, gets stronger with regular practice, then answered reflective questions, including giving examples of the use of growth mindsets in their lives, and giving advice to future first year students. In the social belonging intervention, students read stories about adjusting to university from the perspectives of senior students at the university and answered reflective questions. The stories were based on focus group interviews with senior students. The first story was selected to be from a student that matched the reader's race and gender. The control condition focused on changes in the physical environment.	No significant treatment effects were found across growth mindset intervention, belonging intervention and control groups, or across the full sample. Pre-intervention mindset means (on a scale of 1–6 where higher scores indicate growth mindsets) were 4.74 (mindset intervention group) and 4.77 (control), $p = 0.21$. Post-intervention mindset scores were not reported. Latino/a students who received the growth mindset intervention had significantly higher first-semester GPAs (3.13 vs 2.73 on a scale of 0–4, $p < 0.01$), 2nd semester GPAs (2.97 vs. 2.64, $p < 0.02$) and 1st year cumulative GPAs (3.05 vs. 2.69, $p < 0.002$) than their peers in the control group.
#2	Calisto (2013). Effects of using word problem malleability primes on students. *(PhD Dissertation)*	Quantitative. Quasi-experimental, non-randomised, pre- and post-test control group design. Dependent variables: mindset scores from a 3-item, 6-point Likert mindset survey, math performance on a 10-question class activity, and the number of hard as compared to easy math questions attempted by students on a 30-question challenge activity. Pre-intervention survey given to 2 groups in each of 9 classes in week 2, then groups alternated doing intervention or control activities in weeks 3–5 and weeks 6-8. Participants: 73 non-traditional, Hispanic-, African-, and European-American students, aged 18–58 (average age 27) in an 8-week *Fundamentals of Mathematics* or *College Algebra* course at two separate campuses of a USA Midwestern career college.	Growth mindset messages were included in word problem activities given to students in university mathematics courses in an 8-week semester, e.g. *Sonya read 72 pages of* 'Math Intelligence: With Hard Work and Effort You Can Increase It' versus neutral problems for a control group, e.g. *Sonya read 72 pages of her favourite book.*	Most participants (44 out of 54 with full data sets) had growth mindsets initially, with mindset mean scores of 4.79 (intervention group A) and 4.83 (intervention group B) on a scale from 1 to 6 where scores of 4 and above represent growth mindsets and scores of 3 and below represent fixed mindsets. No significant changes were observed for students' mindset beliefs: post-intervention mindset scores were 4.60 (intervention group A) and 5.19 (intervention group B). Students' performance on a 30-item challenge activity and 10-item mathematics quiz decreased between pre-test and a post-test three weeks later.
#3	Choi (2018). Grit, mindsets, and persistence of engineering students. *(PhD Dissertation)*	Mixed methods. Pre- and post-course survey on mindsets (8-item, 6-point Likert scale), goal orientation (14 items), and self-regulation (20	The mindset intervention was participation in the course *Engineering the Mind* designed to increase growth mindsets. Design-based	Large, matched-pairs rank-biserial correlations were $r = 0.90$ and −0.80 for growth and fixed mindset, respectively, showing that the course

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#	Study	Research design	Details of intervention	Findings
		items). Qualitative data: Reaction papers of thoughts on TED Talks and other media assigned as homework, reflection papers on course topics and activities, strategy documents to plan and evaluate weekly academic goals. Participants: 15 college of engineering students at a large public university in the Western USA, 3 females, 12 males, 4 in 1st-year, 3 in 2nd-year, 6 in 3rd-year, 1 in 5th year, 1 in 6th year.	research and the Transtheoretical Model of Health Behaviour Change were used to guide the translation of theories related to healthy learning dispositions and behaviours into the design of the *Engineering the Mind* course. Course topics included neuroplasticity, mindsets, goal orientation theory, self-regulation.	Engineering the Mind increased growth mindsets and decreased fixed mindsets. Large effect sizes were calculated for growth and fixed mindset: 0.54 and 0.48, respectively. High reliability of the mindset scales was suggested by Cronbach's alpha values of 0.89 and 0.96 for the growth mindset and fixed mindset items on pre- and post-surveys, respectively.
#4	Cutts et al. (2010). Manipulating mindset to positively influence introductory programming performance. *(Conference paper)*	Quantitative. Pre- and post-intervention survey measuring mindset, self-efficacy and positive and negative affect. Survey given in weeks 1–7 of a first-year computer programming course in the UK. Participants: 89 out of 170 students completed both surveys. Tutor groups of 9–17 students. Demographics and survey details not reported.	Three-part intervention in weeks 1–7 of year course: Lecture and reflection; crib-sheet; feedback sheet. (1) Four 10–15-minute tutor talks about an aspect of growth mindsets and then a reflective exercise focusing on students' own learning experience and relating it to mindsets. (2) Crib-sheet of what to try if your computer programme fails, to encourage using different strategies rather than the fixed mindset trait of repeatedly trying the same inappropriate strategy. Half a lecture spent explaining the purpose of the sheet. Tutors answered all student questions with reference to the crib sheet. (3) Adding this text to feedback sheet on fortnightly assignments, 'Remember, learning to program can take a surprising amount of time & effort – students may get there at different rates, but almost all students who put in the time & effort get there eventually. Making good use of the feedback on this sheet is an essential part of this process.'	In the first week, 19 (21%) of the students displayed a fixed mindset, 38 (43%) a growth mindset and 32 (36%) neutral mindsets. The crib-sheet intervention did not affect mindset and test scores. Teaching about mindsets shifted students towards growth mindsets but did not impact class test scores. Between weeks 1 and 7, average mindset scores for students in the mindset training intervention increased from about 3.71–3.93 (on a scale presumed to be from 1 to 6 where higher scores indicate growth mindsets) while mindset scored for the control group decreased from an average of 3.62–3.39, indicating a significant difference between intervention and control groups ($F(1,75) = 4.18$; $p < .044$). There were two-way interactions with mindset training and rubric interventions on both the first test and final exam.
#5	Dringenberg, Shermadou, and Betz (2018). Reactions from first-year engineering students to an in-depth growth mindset intervention. *(Conference paper)*	Qualitative. Exploratory and interpretive. Researchers developed codes for emergent themes based on line-by-line analysis of online written discussions on NVivo. Inter-rater reliability was assessed using the kappa statistic. Participants: 8 first year students in a general engineering program at a large, public, Midwestern University, USA.	Reading group with 2 researcher-participants and 8 students meeting online on the university's learning management system for 5 one-hour sessions in a semester. In each session they discussed their reading of 1–2 chapters of Dweck's (2006) book *Mindset*, responding to 2–3 written discussion prompts adopted from *Mindset*. [Same as second intervention in Dringenberg and Kramer 2019.]	Students reconsidered past interpretations of experiences and projected forward on possible changes towards a growth mindset. Students understood that growth mindset 'was not an all or nothing switch to be flipped'. In data coding, the researchers achieved moderate agreement for the subthemes of *Reinterpreting Past Experiences through the Lens of Mindset—Fixed Mindset* (kappa value of 0.50) and *Growth Mindset* (kappa value of 0.59). For the second theme, *Projecting a Future Utilizing Growth Mindset*, the researchers received a fair agreement (kappa score of 0.25).

#	Study	Research design	Details of intervention	Findings
#6	Dringenberg and Kramer (2019). The influence of both a basic and an in-depth introduction of growth mindset on first-year engineering students' intelligence beliefs. *(Journal article)*	Mixed methods. Pre- and post-semester survey with 4-item, 7-point Likert mindset scale and items on engineering design self-efficacy and orientation to the field of engineering. Independent variables included sex, ethnicity, race, prior experience with engineering, first-generation status and engineer parent/guardian. Qualitative data: written reflections about motivations to study engineering, experiences with engineering problem solving and perspective of own intelligence and how their fixed or growth mindsets will impact their ' pursuit of an engineering degree. Participants: 1st-year students in a general engineering program at a large, public, Midwestern USA university. 72 students participated in the first intervention, 6 of these students went on to join the second intervention.	Two interventions over one semester: Intervention 1: 30-minute introduction to growth mindset theory in the second class of the semester included students self-assessment of their mindsets, an overview of mindset characteristics, research findings on the benefits of growth mindsets, a short video on grit, a think-pair-share discussion on student's own mindsets, and encouragement to promote growth mindsets in individual and team work. Intervention 2: Students were invited to join a mindset reading group that met online, outside of class time, for 5 hour-long sessions to discuss their reactions to the theory.	Neither the in-class introduction nor the more in-depth intervention had a statistically significant influence on students' mindset beliefs. On 1–7 scale where higher values indicate growth mindsets, the in-class introduction had pre-survey mean of 5.22 and a post-survey mean of 5.40. The in-depth intervention had a pre-survey mean of 5.17 and a post-survey mean of 5.50. The in-depth intervention did provide students with a more nuanced understanding of growth mindset theory. A brief introduction into mindset theory is not adequate for significant change in beliefs. Survey items alone may not be indicative of growth mindset and qualitative approaches may be necessary for researchers to gain a more holistic understanding of students' intelligence beliefs.
#7	Fabert (2014). Growth mindset training to increase women's self-efficacy in science and engineering: A randomised-controlled trial. *(PhD Dissertation)*	Quantitative. Randomised control study. No pre-test to conceal the true purpose of the intervention from participants. Post-intervention survey given immediately after intervention. Random allocation to control, treatment and comparison groups following an online demographic survey of age, gender, racial/ethnic background, country of origin, SAT or ACT score, exploratory track, and class standing. Variables: 3-item, 6-point Likert mindset scale (self-form), stereotype disbelief, STEM self-efficacy, intentions to pursue STEM disciplines, number of college courses completed and enrolled for. Participants: 298 women and 191 men in a 'Choosing a major' course at Arizona State University, USA, 5.5% African American/Black; 7.4% Asian American/Pacific Islander; 60.5% White; 14.5% Latina/o; 2.2% Native American/Alaskan Native/Hawaiian; 6.1% Multiethnic/Multiracial, 3.7%	An online growth mindset tutorial and letter writing assignment, completed in under an hour, started in the second face-to-face class meeting. Completion of the online 'pen-pal writing' intervention or alternative contributed 5% of class grades. Students were told to allocate 1.5 hours to completing the task.	At post-test, treatment group mean mindset scores (4.75) were significantly higher ($p <$ 0.001) than the mean mindset scores of both comparison (4.19) and control groups (4.20), where scores range from 1 to 6 and higher scores indicate growth mindsets. Average GPAs of treatment group participants (3.10) were significantly higher than those of control group participants (2.86) but not those of comparison group participants (3.03). Growth mindset belief and stereotype disbelief were positively related ($r = 0.36$, $p < 0.001$); growth mindset belief was positively related to men's STEM self-efficacy ($r = 0.22$, $p < .001$).

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#	Study	Research design	Details of intervention	Findings
		undeclared. Ages 17–27, 85% were 18 years old at the time of the study, 98% in 1st year. 100 students on an 'Engineering, Math, Technology, & Physical Sciences' exploratory track.		
#8	Frary (2018). Encouraging a growth mindset in engineering students. *(Conference paper)*	Mixed methods. Pre- and post-course online survey on Google forms including open-ended questions and a 16-item, 7-point Likert mindset scale. Variables: gender, high school graduation year, paths to Boise State University. Participants: 26 students enrolled for a semester course, Thermodynamics of Materials, taken in the second last year of an engineering degree at Boise State University, USA. 20 males, 6 females, 14 students were at most 3 years out of school, 5 students were 4–9 years out of school, 7 students were more than 10 years out of school.	Four-part intervention. In week 1, students watched Carol Dweck explaining growth mindsets on TEDTalk and Khan Academy videos, followed by class discussion. In weeks 4, 9 and 13 students read articles on growth mindsets and wrote answers to questions. At the beginning of class each day, the instructor shared a growth mindset quote with the students. How quotes related to students' learning and experiences in the course were discussed a few times throughout the semester.	50% of students shifted to a stronger growth mindset post-intervention. Students already had growth mindsets to begin with. At the beginning of the semester, 8 students had strong growth mindsets and 14 more had growth mindsets with some fixed ideas. At the end of the semester, 10 students had strong growth mindsets and 14 more had growth mindsets with some fixed ideas. Greater shifts to growth mindsets were noticed in students who had been out of high school for 10 or more years. Post-course, more students described 'intelligence' through a growth mindset lens instead of a fixed mindset one.
#9	Hoang (2018). Growth mindset and task value interventions in college algebra. *(PhD Dissertation)*	Quantitative. Randomised control study. Pre- and post-intervention survey on mindsets (3-item, 7-point Likert modified to ask about mathematics intelligence), self-efficacy and value perceptions, given in weeks 7–13 of a semester course. Demographic data: gender, age, year of study, ethnicity, race, mother and father's highest education level, developmental courses taken. Post-intervention course grades collected. Participants: 426 students in four sections of a College Algebra course in a large, public university in the Southwestern United States, 79.1% female, aged 18–32 ($M = 18.56$; SD=1.43); 40.1% Hispanic, 39.0% White, 13.6% Black, 7.3% other races/ethnicities; 82.6% in 1st year, 11.0% in 2nd year, 4.9% in 3rd year, and 1.4% in 4th year; 39.9% first-generation students; 5.9% previously took developmental mathematics.	Intervention or control activities in week 9 or 10 and week 11 or 12 in a 13-week semester course. For the growth mindset intervention, students read online about brain growth during learning and wrote a reflection on a time when they strengthened their neural connections in mathematics. Then they read about how effort and appropriate strategies can help in learning mathematics, and the benefits of a growth mindset, and summarised the information in a letter to a future student. For the task value intervention, students rated reasons why college algebra could be useful to them, wrote a letter to future college algebra students on why learning college algebra was personally relevant to them, and wrote a reflection about whether learning college algebra could be beneficial to others. For the control activity, students completed 10 mathematics questions suggested by instructors.	Even after controlling for demographics, course sections, pre-survey scores, and test 1 scores, participants in the growth mindset group ($b = .235$, SE = .097, $p = .035$, $d = .235$) had significantly higher post-survey intelligence beliefs than the control group, confirming that the growth mindset worked in changing intelligence beliefs. Pre-intervention mindset scores on a scale of 1–7 where higher scores indicate growth mindsets were 4.81, sd = 1.35 (intervention) and 5.11, sd = 1.33 (control); post-intervention mindset scores were 5.13, sd = 1.52 (intervention) and 4.93, sd = 1.33 (control).

#10	Reid and Ferguson (2014). Do design experiences in engineering build a 'growth mindset' in students? *(Conference paper)*	Quantitative. Non-randomised control study. Pre- and post-course 27-item mindset scale. In a year prior to this study, mindset scores for 84 1st-year engineering students were taken at the start, middle and end of an academic year. Comparisons of mindset score trends were made between this previous-year group and the study intervention and control groups. Participants: Students at a large, Midwest USA College of Technology taking a 1st-year design-oriented *Introduction to Engineering* course. Control group students were taking a 1st-year course that had no significant open-ended design project. (Number of participants not given.)	Open-ended design project in weeks 8 - 12 of a two-semester *Introduction to Engineering* course.	No significant increase in growth mindsets. While control students showed a slight shift to having stronger fixed mindsets (growth mindset mean 3.54–3.44 on a scale presumed to be from 1 to 6 where higher scores indicate growth mindsets; fixed mindset mean 2.70–2.78 where higher scores indicate fixed mindsets), intervention students showed little change (growth mindset mean 2.89–2.87; fixed mindset mean 3.15–3.11). Mindset scores for a previous year showed a slight, non-significant shift towards fixed mindsets from start of year to end of year (mean for growth mindset items 3.36–3.28; fixed mindset items mean 2.74–2.83).
#11	Rhee, Johnson, and Oyamot (2017). Preliminary findings using growth mindset and belonging interventions in a freshman Engineering class. *(Conference paper)* Rhee and Johnson (2019). Progress on longitudinal study of the impact of growth mindset and belonging interventions in a freshman engineering class. *(Conference paper)*	Quantitative. Randomised control study. Pre- and post-intervention surveys in first and last weeks of a 16-week semester. 3-item, 5-point Likert mindset scale. ANCOVA tests with cumulative GPA and units completed as dependent variables, high school GPA and SAT as covariates. Chi-square tests to determine if interventions impacted retention. Block randomisation by section, in which gender, under-represented minorities (URM)/non-URM, and Pell-eligibility were distributed across conditions as equally as possible. Participants: 441 first-year students in a required Introduction to Engineering course at San Jose State University, USA. 24 students had not declared engineering as a major, about 16% female, at least 18 years old, Asian (39%), Hispanic (21%), and White (20%). 5 semesters of retention and progress-to-degree data for 435 students were analysed in the 2019 paper.	Reading and reflective writing in week 8 of a 16-week semester. Students were assigned to a control, growth mindset or belonging group. The growth mindset group read an article comparing the brain to a muscle that gets stronger with regular practice. The belonging group read excerpts from fictional seniors of various ethnicities and genders describing their integration into the university. Each group wrote a reflective essay in one of thirteen course assignments. The normal course reflection assignment was assigned to the control group.	Before the interventions, under-represented minorities (URMs) had higher growth mindset scores than non-URMs. After 1 year: among women, the growth mindset intervention correlated with lower course performance compared to the control and belongingness groups; among men, the belongingness intervention correlated with higher course performance than in the growth and control; the interventions did not differentially affect course performance among URMs. After 2 years there was no effect of either the growth mindset or the belonging intervention on academic performance, units completed, or retention. After 2 years, for non-Pell-eligible students, retention rates were trending towards significance: Control, 88.0%, Belonging, 93.1% and Growth Mindset, 96.7%. After 2 years the average change of major to engineering were: Control, 83.3% (5 out of 6); Belonging, 81.8% (9 out of 11), and Growth Mindset, 85.7% (6 out of 7).
#12	Robinson (2019). Supporting multiple paths to success: A field experiment	Quantitative. Randomised control study. Pre- and post-intervention surveys including 8-	Three interventions over one semester. In the mindset intervention, students viewed and	Over one semester, no significant difference in mindset was found between the mindset

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#	Study	Research design	Details of intervention	Findings
	examining a multifaceted, multilevel motivation intervention. *(PhD Dissertation)*	item, 6-point Likert mindset scale. Outcome variables: Motivation (values, achievement goals, perceived competence), engineering identity, course grade, GPA, engineering major retention. Interactions with prior achievement (mathematics placement test scores from university records) were also examined to determine whether the intervention effects were stronger for low-achieving students. Participants: 1,021 students in an undergraduate, introductory course required for engineering majors at a large, USA Midwestern university, 75% in 1st year, 24.9% female; 78.4% white, 13.4% Asian/Asian American, 1.9% African American, 3.5% Hispanic/Latino, 2.8% Multiracial; and 11.3% first-generation college students.	responded to video content explaining how the brain builds connections over time and in response to experiences. In the belonging intervention, students viewed video clips of older students who described experiences of adversity in college and how those experiences had been common among first-year students. Students answered comprehension questions after each video and used the concepts they had learned to write a letter to a future student who might be struggling. The third intervention asked students at three times in the semester to write 200-word essays explaining the relevance to their own lives of a concept learnt that week.	intervention and control conditions (Wilks' λ (386, 2) =.99, $p = .12$, partial $\eta^2 = .011$). Overall, there were no statistically significant effects of either intervention on the outcome measures, (motivation, engineering identity, course grades, GPA, engineering major retention) compared to control conditions, and no significant moderating effects based on prior achievement.
#13	Schubert (2017). Exploring the connections between students' mindsets and their writing: An intervention study with a course-embedded writing tutor. *(PhD Dissertation)*	Mixed methods. Pre- and post-intervention surveys using an 8-item, 6-point Likert modified mindset scale with 3 additional questions on talent versus effort. Interviews with students and the embedded writing tutor coded using an inductive approach. Researcher rating of students' first and final drafts of literature reviews to see if growth-minded students revise drafts substantially or perform at a higher level. Participants: 57 engineering students in a writing course at a rural public research university in the USA.	An experienced writing tutor, trained in mindset theory and employed by the University Writing Center, was embedded in a semester course taken by engineering students. The tutor's two tasks comprised the intervention: (1) give an in-class lesson on growth mindset theory and (2) consult with students individually to give them feedback on their literature review drafts.	Data from 36 students who completed pre- and post-intervention surveys showed that students who received the embedded tutoring intervention improved their mindsets more significantly than students in the control and comparison groups. (Values not available.) In addition to becoming more growth-minded, these students' final drafts were also substantially better in terms of organisation, style, and mechanics.
#14	Simon et al. (2008). Saying isn't necessarily believing: Influencing self-theories in computing. *(Conference paper)*	Mixed methods. Control study. Pre- and post-course survey, 6-item, 6-point Likert mindset scale comprising 3 stand-alone items from Theories of Intelligence Scale-Self Form for Adults, 2 items from Dweck's (2000) Questionnaire Goal Choice Items to assess whether students are more concerned with performance or with being challenged in their courses, and 1 item by authors to determine if students viewed programming ability differently from general intelligence. Spearman's rank correlation coefficient	Mid-way through a semester-long computer science course, students were given a 10–15 min lecture on a fixed mindset vs. growth mindset diagram that compared challenges, obstacles, effort, criticism, and the success of others. One week later, students were given a one-page reminder of lecture and asked to write advice for new students, describing a time when they learnt something new other than programming, being specific about the kinds of mistakes they made and how they overcame them, and advising a beginning	Mixed results among groups. Spearman's rank correlation coefficient (ρ) calculations showed that only the 3 items from Theories of Intelligence Scale had the potential for significant correlations ($\rho = 0.48$, 0.55 and 0.28 for statements 1&2, 1&3 and 2&3, respectively). Some statistically significant changes for survey item responses were evident across intervention groups but not all in the same direction. For example, for the two fixed mindset items from the Theories of Intelligence Scale, pre- to post-

		calculations checked which statements had the potential for significant correlations. Focus group with 6 students to discuss interpretations of the 3 Theories of Intelligence Scale items. Open-ended 'explain your choice' questions in post-course survey. Participants: 228 mostly 1st year students in Computer Science 1 courses across 3 institutions: a small, private, liberal arts university located in the United States ($n = 19$, intervention group A), a larger university located in the United Kingdom ($n = 28$, intervention group B), a large North American research-extensive university ($n = 84$ in intervention group C, $n = 97$ in control group).	programmer, emphasising how they can grow their programming intelligence through dealing with programming challenges. The control group had a lecture on learning styles and were asked to write about learning styles.	intervention mean scores (on a 1–6 scale where higher values indicate growth mindsets) were 3.57–4.29 ($p = .033$, intervention B), 3.66–3.28 ($p = .004$, intervention C) and 3.76–3.53 ($p = .011$, control). In a survey in a follow up course, students did recall the intervention but did not think it changed their mindsets.
#15	Willeke (2015). Relationship between whole-person learning and growth mindset in first-generation learners. *(PhD Dissertation)*	Quantitative. Pre-test, post-test, control group, quasi-experiment design. Independent variable: enrolment in a semester-long orientation course, *On Course*. Online pre-test survey in week 1, post-test in last week. Dependent variable: 8-item, 5-point Likert mindset scale. Demographic data: Age, gender, ethnicity, whether parents have attended college, whether parents have completed college, employment status, location. ANOVA on mindset, age, gender, race. Participants: 177 first-year, first-generation students taking *On Course* at one of four community colleges in the USA, 18 years or older.	Exposure to whole-person learning through the orientation course *On Course* curriculum that includes many aspects of whole-person learning, which was hypothesised to develop growth mindsets.	Matched pairs of pre-test and post-test data for 35 students in the intervention and 2 students in the control were too few for within-subjects comparative analysis. No significant difference was found between mindset means for the pre-test (intervention mean = 60.95, sd = 10.02, $n = 85$; control mean = 64.88, sd = 8.31, $n = 18$) and post-test (intervention mean = 61.09, sd = 10.46, $n = 61$; control mean = 65.23, sd = 11.26, $n = 13$) on a scale from 16 to 80 (where higher values indicate growth mindset). An ANOVA analysis showed that the *On Course* curriculum did not have a significant effect on the mindset score for first-generation students over the duration of a first-year orientation course. Black first-generation learners had a significantly higher growth mindset mean score (67.94) than white first-generation learners (60.81) in the post-test.