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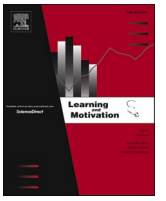

A systematic review and meta-analysis of self-determination-theory-based interventions in the education context

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ABSTRACT

For more than two decades, researchers/schools have adopted Self-Determination Theory (SDT)-based interventions to provide valuable insights into improving education process. The systematic review examined 36 SDT-based intervention studies ($N = 11{,}792$ participants) to understand the nature and effects of these interventions in promoting students' intrinsic motivation and basic psychological needs. Among those studies, 31 included effect sizes related to the effectiveness of the SDT-based interventions. Results from the meta-analysis with the 137 effect sizes extracted from those studies ($N = 9433$ participants) consistently support students' need for autonomy and competence, with evidence of effectiveness of SDT-based interventions across both experimental/quasi-experimental (autonomy: $g = 1.14$, $p < 0.0001$; competence: $g = 0.48$, $p < 0.05$) and pre-post study designs (autonomy: $g = 0.19$, $p < 0.01$; competence: $g = 0.58$, $p < 0.05$). These interventions also demonstrated a partially significant effect in enhancing students' intrinsic motivation within experimental/quasi-experimental frameworks ($g = 0.58$, $p < 0.01$), but no significant overall effect on satisfying students' relatedness ($g = 0.44$, $p > 0.05$). We also discussed the different designs of teacher-centered, student-centered, parent-centered, mentor-mentee-centered, and combined approaches of SDT-based interventions and extracted basic psychological needs support strategies from the included interventions ($N = 119$). Through synthesizing the results from systematic review and meta-analysis, we provide nine research recommendations and future directions for conducting evidence-based and sustainable SDT interventions.

1. Introduction

What explains student behavior in academic settings? Why do some students appear to be more engaged in academic activities than others? What makes some students persevere more than others when facing difficulties and challenges? Providing a psychological

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foundation for human learning and behaviors, self-determination theory (SDT) may help us answer these questions. As a holistic motivation theory, SDT respects and acknowledges differences among learners who have various socioeconomic backgrounds, temperaments, interests, religious values, sexual identities, and neurological processing styles (i.e., how intrinsic motivation and needs support can activate certain brain area associated with learning engagement; Ryan & Deci, 2020). SDT focuses not only on promoting student's academic motivation and performance but can also benefiting students' overall development and well-being by supporting students' three basic psychological needs: autonomy, competence, and relatedness (Kusurkar et al., 2011; Ryan & Deci, 2000; ten Cate et al., 2011).

Given the importance of academic motivation and SDT in education, an increasing number of SDT-based educational interventions have been proposed. However, there has been no standard or guideline for designing SDT-based interventions that are evidence-based and sustainable (Ryan & Deci, 2020). Moreover, it remains unclear how to replicate or extend the use of a well-designed SDT-based intervention to address the developmental decline of academic motivation (Gottfried et al., 2007; Miyamoto et al., 2020).

To address these gaps, a systematic review of the existing SDT-based intervention literature in education is needed. The current review has four main purposes. Firstly, the last published review of SDT related intervention in education was conducted more than ten years ago and only focused on autonomy support (Su & Reeve, 2011). The current review expands the scope and focuses on all three basic psychological needs (i.e., autonomy, competence, and relatedness). Secondly, the current review aims to explore how these interventions were designed to promote student academic motivation across cultures, genders, and ages. Thirdly, this study uses the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach (Page et al., 2021) to identify whether these interventions are effective in promoting students' intrinsic motivation and satisfying students' basic psychological needs (i.e., autonomy, competence, relatedness; Page et al., 2021). Finally, the review will identify and discuss the essential components and contextual factors that researchers should consider when designing an SDT intervention. Two major research questions guide this study:

1. How effective are SDT interventions in terms of (a) improving motivation (i.e., intrinsic motivation), and (b) satisfying students' basic psychological needs for autonomy, relatedness, and competence?
2. Which factors moderate the effectiveness of SDT interventions?

2. Literature review

2.1. Self-determination Theory (SDT)

2.1.1. Motivation

SDT explains human motivation and factors that influence its development, which has great implications in education settings. As an organismic theory, SDT emphasizes that people are prone to self-actualization, and, thus, self-improvement, learning, mastery, and connecting to others are keys to human development (Ryan & Deci, 2020). Such development is fueled by different kinds of motivation. Instead of holding a dichotomous view of motivation (i.e., intrinsic versus extrinsic motivation), SDT describes a continuum for

Internalization

Motivation	AMOTIVATION	EXTRINSIC MOTIVATION				INTRINSIC MOTIVATION
Regulation Style	NA	Exteral Regulation	Introjection		Identification	Integration	NA
			Guilt	Ego			
Attributes	1. Lack of perceived competence 2. Lack of value 3. Non relevance	1. External rewards or punishment 2. Compliance 3. Reactance	1. Guilt towards use of time 2. Guilt towards use of energe	1. Ego involve 2. Focus on approval from self and others	1. Personal importance 2. Conscious valuing of activity 3. Self-endorsement of goals	1. Congruence 2. Synthesis and consistency of identifications	1. Interest 2. Enjoyment 3. Inheret satisfaction
Perceived Locus of Causality	Impersonal	External	Somewhat External	Somewhat External	Somewhat Internal	Internal	Internal

Fig. 1. Self-Determination Theory's Taxonomy of Motivation.
Note: Adopted from Ryan & Deci (2020) and Wang (2021).

motivation that includes amotivation, four types of extrinsic motivation, and intrinsic motivation (see Fig. 1; Ryan & Deci, 2020; Wang, 2021).

Intrinsic motivation was the primary focus of early research on SDT. In educational settings, intrinsically motivated students show pure interest, joy, and satisfaction toward learning (Deci et al., 1981). However, it is unrealistic to assume that students will be intrinsically motivated all the time, or that every student is intrinsically motivated towards learning. Accordingly, SDT researchers describe extrinsic motivation based on an individual's regulatory style and the level of internalization (Wang & Wind, 2020). SDT defines a student who is motivated and regulated only by external rewards or punishment as *externally regulated*. As all the motivation sources in this type of extrinsic motivation are external, students in this category will feel controlled and non-autonomous. Moving up on the motivation continuum is *introjected regulation*, which shows partial internalization, such that students' behaviors are regulated by performing better than others, or avoidance of anxiety, shame, or guilt for bad grades or use of time and energy. As this type of motivation is ego-involved and anxiety/guilt/shame-associated, this type of extrinsic motivation is "internally controlled."

Unlike external regulation and introjected regulation, the other two types of extrinsic motivation, *identified regulation* and *integrated regulation*, are considered autonomous (Vansteenkiste et al., 2018). Within the identified regulation category, students acknowledge the importance of learning and are more likely to learn voluntarily. In integrated regulation, students not only identify the importance of learning but also find that learning could support other core interests and values. For instance, a medical student believes that helping others is part of his identity, so he acknowledges that what he learned at school could allow him to help more patients and thus support the development of his identity. Even though identified and integrated regulations could solicit a high degree of volition or willingness to learn, they are still different from intrinsic motivation. The source of identified and integrated regulation learning actions is *value*. As a result, students evaluate whether certain efforts are worthwhile before engaging in them. In contrast, the foundation of intrinsic motivation is internal enjoyment and satisfaction (Ryan & Deci, 2020). The last type of motivation, amotivation, is rarely discussed, but also very common in the classroom setting (Schwan, 2021). For example, amotivated students may show no interest in learning at all and will give up or drop out of school.

In general, SDT sees amotivation, external regulation, and introjected regulation as less-ideal types of motivation, with the last two as controlled motivation. On the other hand, identified regulation, integrated regulation, and intrinsic motivation are considered autonomous and ideal types of motivation (Ratelle et al., 2007; Vansteenkiste et al., 2009). Over approximately 50 years of research, SDT studies have found that amotivation and controlled motivation negatively affect engagement, learning, and wellness, while autonomous motivation may promote students' academic performance and well-being (Ryan, 2023). SDT researchers believe that satisfying three basic psychological needs could support students in developing a more autonomous type of motivation (Ryan & Deci, 2019).

2.1.2. Three basic psychological needs

In order for students to progress toward intrinsic motivation, it is essential to provide external support for their basic psychological needs: autonomy, competence, and relatedness. Reflecting this idea, SDT researchers have identified strategies to support students related to these needs (Durksen et al., 2016; Müller et al., 2021). The most studied basic psychological need, *autonomy*, is a sense of ownership in the learning environment. This need can be supported by providing students with choices and using non-controlling language in the classroom. *Competence* is the sense of capability and the feeling that one can be successful in learning and achieving. Teachers and parents can support this need by giving positive feedback, providing optimal challenges, and designing well-structured learning materials. Lastly, *relatedness* is a sense of connection and belonging. Students need to feel inclusion in their learning environment to have a better learning experience and be motivated to thrive.

Stemming from the concept of different types of motivation and basic psychological needs, SDT has made two key theoretical contributions to education: 1) identifying the important roles that motivation plays in students learning, engagement, academic performance, and well-being; and 2) specifying students' three basic psychological needs and the outcomes associated with needs satisfaction and thwarting.

2.2. SDT Interventions

As a prominent theory in modern psychology, researchers have adopted SDT in numerous interventions in multiple domains, such as business, education, and physical therapy (Hall et al., 2022; Ntoumanis & Standage, 2009; van Tuin et al., 2020). In the education domain, many interventions endeavored to promote students' cognitive abilities (e.g., critical thinking) or test scores (e.g., Deming, 2009; Dewey & Bento, 2009; Kelly & Rutherford, 2017; Vidergor, 2018), whereas SDT interventions focus more on non-cognitive factors (e.g., academic motivation and basic psychological needs). Su & Reeve (2011) conducted a meta-analysis on the effects of autonomy support on students' intrinsic motivation. The results showed that these autonomy-support interventions had a large effect ($d = 0.632$) on improving teachers' autonomy-support mindset and skills, but they did not report how such intervention influence students. In the last decade, a number of rigorous and innovative SDT-based interventions emerged which targeted at students' intrinsic motivation and basic psychological needs. For example, one SDT-based intervention targeted at students' intrinsic motivation showed that after their basic psychological needs were supported, students became more intrinsically motivated towards learning (Kiemer et al., 2018). Another recent study showed that a SDT-based mindful attention intervention could support students' psychological needs for autonomy, competence, and relatedness (Elphinstone et al., 2021). Moreover, there were efforts to conduct SDT-based intervention online and using modern technology (e.g., using computer games). For instance, Patall and her colleague (2022) conducted online research to promote college students' agentic mindset and basic psychological needs satisfaction. Educators also used computer games to enhance students' learning motivation (e.g., Blankenburg et al., 2016; Mckernan et al., 2015).

A systematic review and meta-analysis of motivation-based physical activity interventions in schools was also conducted (Kelso et al., 2020). This study found that school-based physical activity interventions may be effective in increasing students' enjoyment, perceived autonomy, and intrinsic motivation towards physical activities. Although researchers have applied numerous SDT-based intervention studies in recent years, a systematic review and meta-analysis of SDT-based intervention within the academic domains is still missing. As a result, there is currently no cumulative evidence related to the use and effects of SDT-interventions to support students' intrinsic motivation and basic psychological needs.

The current review expands the scope of the previous meta-analyses and focus on SDT-based interventions in academic settings that promote students' autonomous motivation, autonomy, competence, and relatedness. There are three main purposes of this systematic review and meta-analysis: 1) to provide a comprehensive profile of SDT-based intervention in education; 2) to identify the effectiveness of these interventions in terms of promoting students' autonomous motivation, autonomy, competence, and relatedness; and 3) to discover the specific factors that make the intervention effective in different cultures, genders, and age groups with both qualitative and quantitative syntheses of the previous literature. With our review, we aim to guide researchers and practitioners in conducting SDT-interventions in an evidence-based, systematic, and sustainable manner.

3. Method

3.1. Literature search

We adopted the PRISMA approach to guide our systematic review process (see Fig. 2). The first author selected and reviewed the ten most-frequently cited educational psychology systematic review and meta-analysis articles (Appendix I) from Google Scholar published after 2010 to identify the relevant databases. Nine databases appeared more than twice: 1) PsycINFO; 2) ERIC; 3) Web of Science; 4) Google Scholar; 5) Medline; 6) Scopus; 7) ScienceDirect; 8) PSYNDEX; and 9) ProQuest Dissertations. We extracted studies using variations and combinations of the keywords listed below:

a) *"self-determination theory" AND "intervention" AND "education" NOT ("physical education" OR "sports" OR "athlete") NOT ("disabled" OR "disability")*

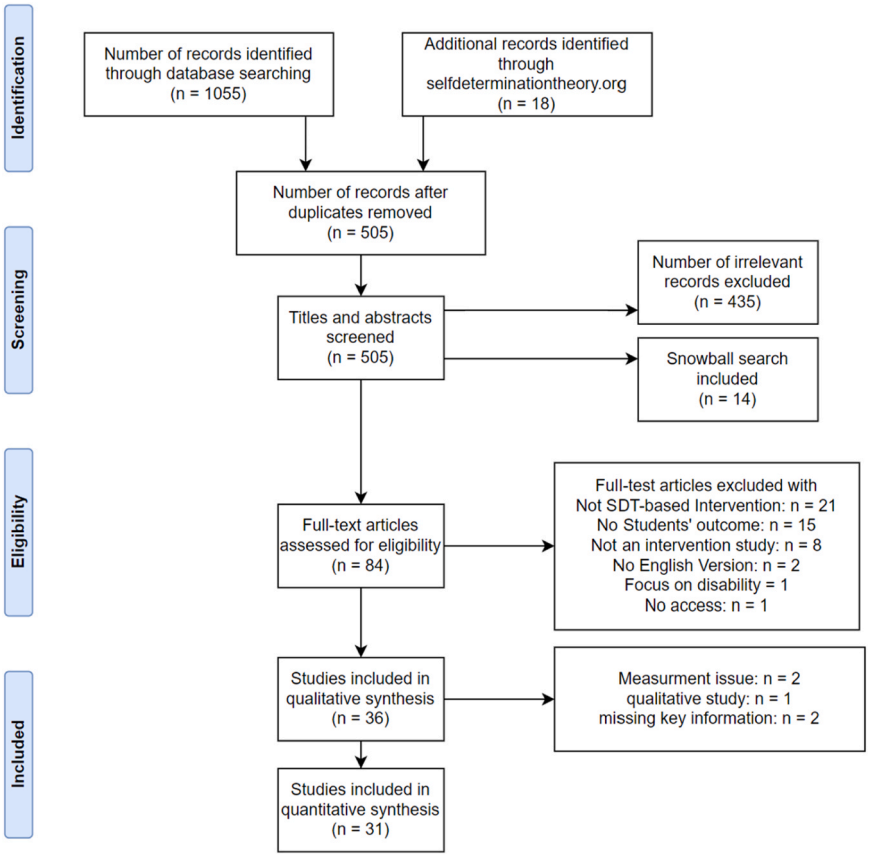

Fig. 2. The PRISMA Flow Diagram.

b) *"self-determination theory" AND ("autonomy support" OR "autonomous support" OR "autonomy supportive") AND "intervention" AND "education" NOT ("physical education" OR "sports" OR "athlete") NOT ("disabled" OR "disability")*
c) *"self-determination theory" AND ("relatedness" OR "related" OR "relatedness needs satisfaction" OR "relatedness need fulfillment") AND "intervention" AND "education" NOT ("physical education" OR "sports" OR "athlete") NOT ("disabled" OR "disability")*
d) *"self-determination theory" AND ("competence" OR "competency" OR "competencies") AND "intervention" AND "education" NOT ("physical education" OR "sports" OR "athlete") NOT ("disabled" OR "disability")*

Specifically, we used each search combination once in the database. In total, we searched each database four times using each of the sets of keywords listed above.

We selected 1975 as our starting year for our search, because this is the year when SDT was first formally introduced (Deci & Ryan, 1975). The first author also manually searched the empirical studies listed on the Center for Self-determination Theory Website: https://selfdeterminationtheory.org/ to address the possible gap that not all relevant studies are indexed adequately within these platforms. These search methods yielded 1073 research articles. After eliminating duplicates, the results yielded 505 unique studies (see Fig. 2), which were then screened using the inclusion criteria described in the following section. The authors also "snowballed" included articles by searching the reference lists in these publications to find studies that we missed during the initial electronic database search. The search process ended in June 2022.

3.2. Inclusion criteria

To address our research questions while preventing publication bias, our review included publications in peer-reviewed journal articles, book chapters, as well as dissertations. We included studies in our systematic review in which 1) the authors explicitly labeled the study as a SDT-based intervention or training; 2) the intervention used an experimental or quasi-experimental design with intervention group(s) and control group(s), pre-post-tests, qualitative methods, or a mixed-method design; 3) the context of the study was in education settings with students, parents, teachers, or other school personnel as participants; and 4) the studies were published in English or had been translated into English; 5) the studies included student outcomes on intrinsic motivation, autonomy, competence, or relatedness support; 6) the studies did not focus on physical education contexts or disabled and special education students. We made the decision to exclude physical education from our review for several reasons that we believe strengthen the focus and coherence of our work. Firstly, a recent comprehensive study has already shed significant light on Self-Determination Theory (SDT) interventions within the realm of physical education, providing an in-depth analysis that our review could not meaningfully expand upon without redundancy (Raabe et al., 2019). Secondly, the intrinsic nature and objectives of physical education markedly differ from those of the other academic subjects that we included in our review. Unlike traditional academic disciplines that primarily engage cognitive and theoretical learning, physical education uniquely prioritizes physical activity, motor skills acquisition, health education, and fostering a lifestyle of physical activity (Erwin & Castelli, 2008; Sallis & McKenzie, 1991). These distinct characteristics and outcomes underscore the necessity of considering physical education through a specialized lens, separate from the broader educational interventions our review focuses on.

In developing our search strategy for this meta-analysis, we prioritized the inclusion of primary research studies to capture the most recent and direct evidence available in the field of SDT intervention. This decision was guided by our aim to present a comprehensive and up-to-date analysis that extends beyond the findings of seminal systematic reviews and meta-analyses, such as the influential work by Su and Reeve (2011). While we recognize the substantial value of such reviews in summarizing and synthesizing existing knowledge, our focus on original research articles was intended to avoid potential overlap and to delve into new contributions to the literature. At the time of our search, we noted a scarcity of recent review papers on our specific topic, which further supported our approach. Nonetheless, we acknowledge that previous reviews have played a crucial role in shaping our research questions and methodology. Their insights provided a valuable context for our investigation, enabling us to position our findings within the broader scholarly discourse. This meta-analysis aims to complement and expand upon the foundational analyses provided by earlier reviews, offering a fresh perspective based on the latest empirical evidence.

For our meta-analysis, we only included studies in which the intervention used an experimental or quasi-experimental design with intervention group(s) and control group(s), or pre-post-tests. The other criteria were the same as for the systematic review.

3.3. Article review process

To facilitate the article review process, we exported the title, article types, year of publication, authors' names and affiliations, abstract, keywords, and the journal name of the identified articles to a Microsoft Excel spreadsheet (Pahlevan-Sharif et al., 2019). The first and third authors reviewed the recorded titles and abstracts independently based on the criteria stated above. The articles that did not fit the criteria were eliminated. After both authors finished their lists of included articles, the fifth author compared the lists and resolved any discrepancies (Tawfik et al., 2019). After finalizing the list, the first and third author completed full-text reading independently. A discussion among the first, second, and third authors resolve the discrepancies in the full-text review process (Ahn & Kang, 2018).

3.4. Coding

When the list of included articles was finalized, the first and fifth authors coded the papers using a systematic data extraction form.

We modified the coding form demonstrated in Slemp and his colleagues' (2021) study to make it more suitable for our research purpose. Studies were coded using twelve categories: 1) year of publication; 2) study design (e.g., experimental design, quasi-experimental design, and mixed-method design); 3) sample size (i.e., students sample, teacher sample, and parent sample size); 4) students' age; 5) subjects/major (e.g., math, STEM, and education major); 6) geographic origin (country); 7) intervention platform (in-person/online); 8) intervention approach (teacher-centered, student-centered, parent-centered, mentor-mentee, combined); 9) intervention duration; 10) primary goals (primary dependent variables). The third author compared the systematic data extracted by the first and fifth authors to identify any discrepancies, and all the authors except the fourth author discussed the results together to correct any mistakes in coding (Ahn & Kang, 2018).

A total of 2088 codes were independently identified by each coder, comprising 432 related to study characteristics and 1656 to meta-analysis data. Differences were observed in 89 of these instances, representing 4.26 % of the total codes. These discrepancies were minor and appeared across nearly all coded characteristics, with the most frequent differences noted in coding the primary dependent variables, likely because of the subjective nature of these judgments. Even so, the number of disagreements in this category was relatively low. Discrepancies related to the calculated effect size were noted only in two cases, making up 2.2 % of all discrepancies. All differences were eventually reconciled either through discussion or by consulting a third independent coder. No formal reliability estimate was computed for this coding due to the resolution of all discrepancies and the independent double-coding of each study. Previous research suggests that such a method typically yields high reliability (Patall et al., 2008; Rosenthal, 1987). To obtain a formal reliability estimate, at least three additional coders would have been necessary to replicate the coding process on a subset of studies for comparative analysis. Overall, the interrater reliability among coders was notably high, with an agreement rate of 95.74 %.

3.5. Risk of bias assessment

The *Cochrane Handbook for Systematic Reviews of Interventions* risk-of-bias assessment tool was adopted to perform a quality assessment (Higgins et al., 2019). The first and third authors evaluated the included studies independently using seven criteria: 1) allocation concealment; 2) blinding of outcome assessment; 3) blinding of participants and personnel; 4) incomplete outcome data (>= 6 weeks); 5) incomplete outcome data (2–6 weeks); 6) random sequence generation; 7) selective reporting. Each study was coded as either *high risk*, *low risk*, *not applicable (NA)*, or *unclear risk*. Chance-corrected inter-rater reliability was evaluated using Cohen's Kappa (Altman, 1999). Specifically, the R function *Kappa* from *vcd* package was used to compute the Kappa value. Result represented a strong level of agreement ($k = 0.84$, 95 % CI, 0.57 to 0.93; McHugh, 2012). Differences in ratings were resolved by discussion among the first, second, and third authors. We did not assign a global score for each study because most of the quality assessment criteria were designed for randomized controlled trials and medical studies. For example, studies with one *high risk* score were rated as moderate quality, and two or more *high risk* scores were rated as low quality. Since our review included other types of studies (e.g., qualitative studies and pre-post design), the same global rating scheme could not be applied to all studies.

3.6. Effect size calculations

To calculate the mean effect size, we used the standardized mean difference (SMD; i.e., Hedges' *g*) calculated using the *metafor* package in R (Crystal-Ornelas, 2020; Hedges & Olkin, 1985). The SMD has two major advantages: 1) it can statistically correct for variance when sample sizes are small; 2) it can synthesize the data that were measured on different scales (Hedges, 1981). Since researchers measured motivation and basic psychological needs using different scales, the second advantage of SMD is especially useful in our review. In *metafor,* when calculating Hedges' *g,* all measurements will be converted to a unitless scale, and the sample size of each study is considered. The formula for calculating Hedges' g is:

$$Hedges'g = \frac{M_1 - M_2}{SD^*_{pooled}}$$

Where $M_1 - M_2$ is the difference in means, and SD^*_{pooled} is the pooled and weighted standard deviation (Hedges, 1981). Next, we use the new effect size calculated for each row of data and the variance for each effect size to generate an overall single effect size using random effects models. We had two main reasons for choosing random effects models over fixed effects models: 1) The strict assumptions of fixed effects models are unlikely to hold in educational meta-analysis, such as the assumption that all effect sizes come from the same underlying population; 2) even though the main effect we are studying might be consistent (e.g., changes in students' motivation) we want to account for the variation both within a study as well as between the different studies in the current meta-analysis (Koricheva et al., 2013). No extra steps are needed for weighted analysis, as each study was automatically weighted in the *metafor* package.

Moreover, since some effect sizes were extracted from the same study (e.g., studies reporting results for more than two groups/time points), we took two steps to address the independence between effect sizes. First, because the effect sizes were not completely independent, we treated the *lastname* variable as a random effect (Cameron & Esserman, 2018). Second, we implemented robust variance estimation (RVE) using the *robumeta* package in R. The *sensitivity()* function in *robumeta* provided the average effect size and associated standard error for difference values of rho in the interval (0,1), in which 0 means completely independent while 1 means completely dependent (Fisher & Tipton, 2015). The result indicated no dependency, so we reported the outcome as independent to avoid losing valuable data. Even though it is not essential for random effects models, we also tested heterogeneity in the data using Specifically, we used the *funnel()*and Egger's test (*regtest*) functions in *metafor* to identify potential publication bias (Egger et al., 1997). When Egger's

test was significant (i.e., there is publication bias), we adopted the trim-and-fill procedure to estimate the actual effect size (Belland et al., 2017; Duval & Tweedie, 2000; Schwarzer et al., 2015). We interpreted effect sizes using Cohen's (2013) recommendations of small ($g = 0.2$), medium ($g = 0.5$), and large ($g = 0.8$).

3.7. Moderator analysis

We used a moderator analysis to explore the effects of SDT interventions across four different dependent measures. Based on previous self-determination theory meta-analyses and the characteristics of the studies in the current review, we included six potential moderators in our analysis: intervention approach, duration of the intervention, study design, students' age, students' gender, and geographic origin (Howard et al., 2021; Ng et al., 2012; Vasconcellos et al., 2020). We included the first three moderators to understand differences in the effectiveness of intervention approaches. We included the final three moderators to test the generalizability of SDT interventions across demographic groups (Ryan & Deci, 2020). There were five categories for the intervention approach (teacher-centered, student-centered, parent-centered, mentor-mentee, combined) for the intervention approach, six categories for the duration of the intervention (less than/equal to one day, more than one day and less than/equal to one month, more than one month and less than/equal to three months, more than three months and less than/equal to six months, more than six month and less than/equal to one year, more than one year), three categories for study design (experimental, quasi-experimental, pre-post design), three categories for students' age (i.e., 7–12, 13–18, and over 18), two categories for student's gender (male and female) based on the percentage of the participants, and four categories for geographic origin (i.e., Asia, Europe, North America, and South America). For each subgroup within each potential moderator, we calculated the number of studies related to that subgroup (k), the effect size for each characteristic (b), the standard error (SE) for each characteristic, 95 % confidence intervals for the mean, and p-values. We used the same procedures as outlined above for the main effect analyses for the moderator analysis.

4. Results

4.1. Systematic review

As shown in Fig. 2, we identified a total of 505 studies after removing duplicate records ($n = 568$). An additional 18 studies were identified through selfdetermination.com. First, we screened all titles and abstracts and removed those that did not meet the inclusion criteria. In the next step, two researchers screened 84 papers independently for eligibility. After removing 58 studies, 36 full-text articles ($N = 11{,}976$ participants) met the inclusion criteria. The study characteristics are presented in Table 1.

The included interventions provided valuable information on how to successfully improve students' intrinsic motivation and satisfy students' three psychological basic needs. We described five characteristics of the included studies.

4.1.1. Geographic origin

The authors coded the geographic origin of the interventions based on the location of the intervention and the data collection site. All 36 included studies clearly reported the location of the intervention. Fig. 3 indicates the geographic origin of the interventions. The majority of studies were conducted in Western and developed countries. Most interventions ($n = 14$) were conducted in Europe., There were 10 SDT interventions conducted in Asia, 10 in North America, and two in South America. We did not identify any intervention studies in Australia or Africa.

4.2. Age groups

More intervention studies were conducted with late childhood and adolescent samples compared to other life stages. As Fig. 4A shows, 13 studies were conducted with participants who were between 13–18 years old, and 12 studies were conducted with 7–12 year-olds. There were also 7 studies conducted with young adults. Four studies did not report students' age, and no studies were identified with participants who were younger than seven years old.

4.3. Intervention approach and duration

As Fig. 4B demonstrates, more than one third of the intervention studies provided teacher training to help optimize students' motivation in school. In general, there were five types of interventions: teacher-centered, student-centered, parent-centered, mentor-mentee, and combined approach. Among these interventions, the student-centered approaches varied substantially in terms of intervention design, whereas the teacher- and parent-oriented approaches shared similarities. Specifically, the teacher-centered and parent-centered interventions were primarily focused on developing motivation training programs to help teachers and parents understand students'/children's motivation and to better support students'/children's basic psychological needs (e.g., Jacob et al., 2019). The student-centered interventions were directly targeted to students, which included competition (Blankenburg et al., 2016), online discussion (Butz & Stupnisky, 2017), and psychoeducation programs (Moll-Khosrawi et al., 2021). The mentor-mentee approach focused on providing support to a special group of students in alternative schools (e.g., Dell et al., 2018). The combined approach included training for teachers, students, and, in one study, also parents (Ivanov, 2015).

Moreover, the duration of these studies also varied. The shortest intervention was 30 min (Patall et al., 2022), while the longest one was 3 years (*Toshie & Osamu, 2017). Fig. 5 presents the duration of different intervention studies. Most studies lasted between 1

Table 1
Study characteristics.

Author (s)	Year	Study Design	Detailed method	Sample Size	Age	Subject	Country	Intervention design	Intervention duration	Analysis of intervention effect	Primary Dependent Variables
										MANOVA	Interest; effort; pressure; relatedness; perceived autonomy support; external regulation; integrated regulation
Kaplan & Assor	2012	Pre-post test	NA	420	12.5	NA	Israel	teacher-centered	2 year	*t*-test	Positive emotions; negative emotions; class violence; choice-focused dialogue; relevance-focused dialogue; criticism supporting dialogue
Kiemer et al.	2018	Quasi-experiment design; Mixed Method	NA	226	15.67	STEM	German	teacher-centered	1 year long	Relative change	Students' perception of autonomy support & competence support; self-determination
Blankenburg et al.	2016	Experimental design	cluster-randomized trials	474	11.2	Science	German	Student-centered	10 month	RM-ANOVA	Students' willingness/interest to participate in science competition
Assor et al.	2018	Quasi-experimental design	NA	2124	10.3	NA	Israel	teacher-centered	22 month	ordinary least square	Student perception of classmates caring; student-reported physical violence; student perception of teacher as actively responding to violence; student perception of teacher as controlling; student perception of teacher as autonomy-supportive; teacher internalization of SDT principles
Dell et al.	2018	Qualitative study	NA	45	20	Engineer	US	mentor-mentee	4 years	NA	NA
Author(s)	Year	Study Design	Detailed method	Sample Size	Age	Subject	Country	Intervention design	Intervention duration	Analysis of intervention effect	Primary Dependent Variables
Brandenberger et al.	2017	Quasi-experimental design	NA	348	12.75	Math	Swiss	teacher-centered & student-centered	1 year long	MANCOVA	Math achievement; perceived support of the autonomy, competence, relatedness psychological needs; self-determined motivation; self-concept
Jacob et al.	2019	Quasi-experimental design	cluster sampling	217	21.25	Teacher Education	German	teacher-centered & student-centered	unclear	RM-ANOVA	Achievement emotion; perceived autonomy support; instructional characteristics
Villiger et al.	2012	Experimental design	cluster sampling	713	9.97	Reading	Swiss	teacher-centered & parent-centered	1 year	Multilevel analysis	Reading motivation (intrinsic or extrinsic); reading self-concept; reading enjoyment; reading comprehension; grade in reading
Butz & Stupnisky	2017	Experimental design; Mixed method design	NA	83	31.18	MBA, MPA, MS-Avi	US	student-centered	5 week	paired sample *t*-test	Self-efficacy for relatedness development; autonomy, relatedness, competence need

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Table 1 (*continued*)

Author (s)	Year	Study Design	Detailed method	Sample Size	Age	Subject	Country	Intervention design	Intervention duration	Analysis of intervention effect	Primary Dependent Variables
											satisfaction; student motivation; perceived success
Grolnick et al.	2021	Experimental design	random controlled trail	57	10	NA	US	parent-centered	6 week	RM-ANOVA	Parenting issues, parent autonomy support, structure, and involvement; parent efficacy; child symptoms; SDT concepts and strategies
Montero-Carretero et al.	2021	Quasi-experimental design	cluster sampling	79	11.13	Teacher Education	Spain	teacher-centered	unclear	one way ANCOVA	Teacher's teaching style, basic psychological needs (BPNs): student autonomy, competence & relatedness, self-determined motivation, tolerance and respect, moral identity, harassment and victimization
Niemiec & Muñoz	2019	Quasi-experimental design	cluster sampling	167	15	English	Colombia	teacher-centered	10 h	independent *t*-test	Autonomy support; autonomous self-regulation; basic psychological need satisfaction; well-being; subjective vitality scale; positive affect; negative affect
Toshie & Osamu	2017	Quasi-experimental design	cluster sampling (convenient sampling)	47	19.5	English	Japan	teacher-centered	3 years	two-way ANOVA	Autonomy; competence; relatedness
Author(s)	Year	Study Design	detailed method	Sample Size	Age	Subject	Country	Intervention design	Intervention duration	Analysis of intervention effect	Primary Dependent Variables
Tessier et al.	2022	Experimental design	cluster sampling	819	13.8	Multiple subjects	France	student-centered	10 month	Linear mixed model	Student: students' perception of teachers' motivation style; students' motivation; emotion regulation; school satisfaction.
						Science	Singapore	teacher-centered	1 year	standardized mean differences (*g*)	Achievement; students' motivation; self-regulation; engagement; sense of competence; interest; task goal orientation; education aspiration; career aspiration; engagement
Ivanov	2015	Experimental design	random controlled trail	132	NA	Education	US	teacher-centered & student-centered	55 min	factorial ANOVA	Interest; utility value; performance test; sense of autonomy
Cole et al.	2018	Experimental design	random controlled trail	246	20	Math	US	Student-centered	30 min	Scheffe's post hoc tests	Autonomy, effort, extrinsic motivation
Phillips	2015	Experimental design	random controlled trail	863	12.5	NA	US	student-centered	1 year	Linear fixed effects regression	Emotional well-being (life satisfaction aspect); effort with schoolwork; attitude

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Table 1 (*continued*)

Author (s)	Year	Study Design	Detailed method	Sample Size	Age	Subject	Country	Intervention design	Intervention duration	Analysis of intervention effect	Primary Dependent Variables
											towards school; prosocial behavior; trust
Moll-Khosrawi et al.	2021	Pre-post test	NA	145	NA	Medical	Germany	student-centered	3 months	multilevel model	Controlled motivation; identified motivation; actual vs. simulated bedside interactions
Lozano-Jiménez et al.	2021	Quasi-experimental design; Mixed method design	cluster sampling	220	29	Multiple subjects	Colombia	teacher-centered	6 months	RM-ANOVA	Autonomy support; controlling style; basic psychological needs, motivation, involvement; controlled motivation; autonomous motivation.
Zheng et al.	2020	Pre-post test	NA	43	NA	Health	China	student-centered	3 months	two-way ANOVA	Health literacy; needs satisfaction; perceived autonomy support, competence, relatedness
Author(s)	Year	Study Design	detailed method	Sample Size	Age	Subject	Country	Intervention design	Intervention duration	Analysis of intervention effect	Primary Dependent Variables
Zhang et al.	2020	Quasi-experimental design; Mixed method design	cluster sampling	147	14	Physics	China	teacher-centered	9 months	General linear models with repeated measures	Autonomy/learning engagement; student perception about teacher autonomy; supportive behaviors; satisfaction of autonomy needs, and four aspects of learning engagement.
Law & Liu	2021	Experimental design	random controlled trail	55	18.2	NA	China	student-centered	1 month	RM-ANOVA	Basis needs and adjustment; basic need satisfaction; autonomy; competence; relatedness
Chiu et al.	2021	Experimental design	random controlled trail	358	14.4	STEM	Hong Kong	teacher-centered	6 months	ANCOVA	Teachers: Perceived competence and intrinsic motivation; Students: perceived competence, intrinsic motivation, and cognitive engagement
Bortoli et al.	2017	Experimental design; Quasi-experimental design	random controlled trail	249	14.5	NA	Italy	teacher-centered	4 months	RM-ANOVA	Mastery climate; performance climate; pleasant/functional PBS states; unpleasant/dysfunctional PBS states; PBS index; intrinsic motivation; identified regulation; external regulation; amotivation
Patall et al.	2022	Experimental design	random controlled trail	1165	18	Psychology, physics and, chemistry courses	US	student-centered	30 min	ANOVA & structural equation modeling	Agentic mindset; engagement; need satisfaction; personal interest; perceived autonomy support
Chiu	2022	Experimental design	random controlled trail	342	15	Science, math, and technology	China	teacher-centered	12 weeks	ANOVA	Autonomy, competence, relatedness, and STEM interest and identity, in addition to greater intentions to choose elective STEM subjects
Waterschoot et al.	2019	Experimental design	random controlled trail	126	10.5	Painting	Belgium	Student-centered	45 min	MANOVA	Intrinsic motivation; autonomy; competence need satisfaction; vitality; intended persistence

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Table 1 (*continued*)

Author (s)	Year	Study Design	Detailed method	Sample Size	Age	Subject	Country	Intervention design	Intervention duration	Analysis of intervention effect	Primary Dependent Variables
Author(s)	Year	Study Design	detailed method	Sample Size	Age	Subject	Country	Intervention design	Intervention duration	Analysis of intervention effect	Primary Dependent Variables
Guay et al.	2016	Experimental design	cluster sampling	277	7.23	NA	Canada	teacher-centered	2 days	ANCOVA	Student: intrinsic regulation; identified regulation; control regulation; perceived competence; relatedness to teachers; Teacher: collaboration, autonomy support, authentic tasks, involvement, and structure.
Gorissena et al.	2015	Quasi-experimental design	NA	69	10	Geography	Netherlands	Student-centered	2 weeks	Multiple regression analyses	Performance; academic self-regulation style; task motivation and need fulfilment for completing the essay questions
Baten et al.	2020	Experimental design	cluster sampling	479	9.41	Math	Belgium	Student-centered	unclear	MANOVA	Mathematical abilities; motivation for mathematics; manipulation check; disengagement; need satisfaction and frustration: autonomy, competence, relatedness; intrinsic motivation; behavioral challenge seeking; interest; irritation
Froiland	2010	Quasi-experimental design	NA	30	Not provided	NA	US	parent-centered	7 weeks	ANCOVA	Autonomy, intrinsic motivation, parents' perception of children's intrinsic motivation, parent satisfaction, treatment integrity for autonomy support
Joussemet et al.	2014	Pre-post test	NA	44	10	NA	Canada	parent-centered	8 weeks	MANOVA	Affiliation; autonomy aupport (attitude); autonomy-supportive parenting skills; child mental health problems; child reports: perceived parental structure; perceived parental affiliation; perceived parental autonomy support; positive indicators of mental health
Van Loon et al.	2012	Experimental design	cluster sampling	320	12.5	Advertising creator	Netherlands	Student-centered	1.5 h	General linear model univariate ANOVA	Perceived autonomy, perceived competence, and intrinsic motivation; learning outcomes
Simões & Alarcão	2014	Experimental design	cluster	317	11.5	NA	Portugal	mentor-mentee	6 months	MANCOVA	Basic need satisfaction in relationships scale; physical well-being; parent relations & autonomy; social support & peers; school environment; perceived competence in learning; children's hope

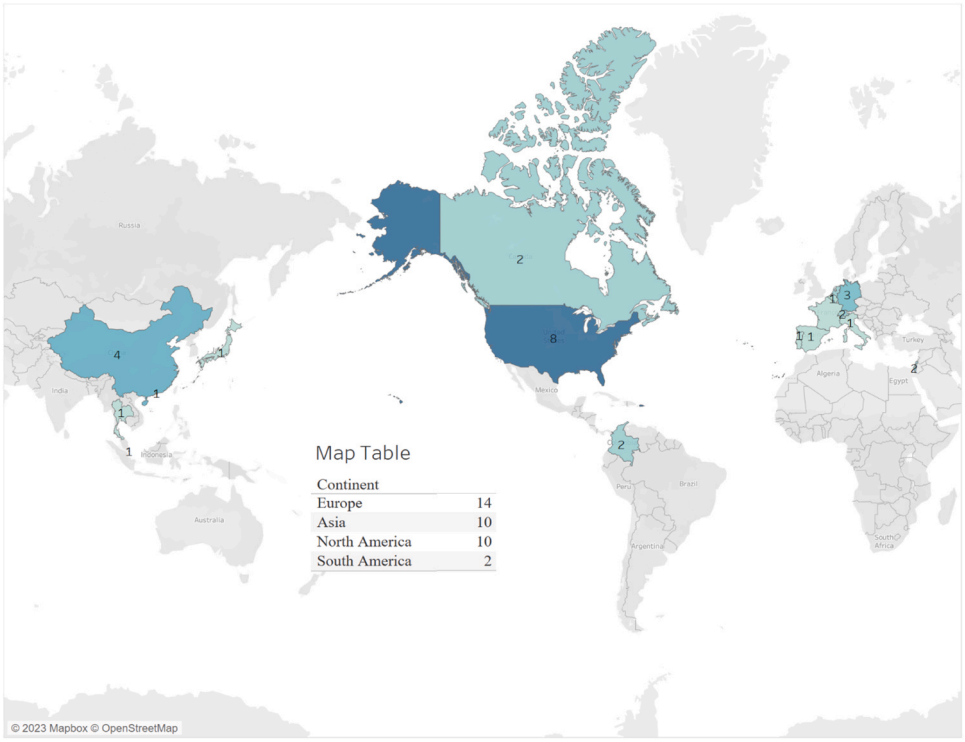

Fig. 3. Geographic origin of the interventions.

month and 1 year.

4.4. Assessment of intervention outcomes

The majority of studies adopted a quantitative approach (i.e., experimental design, quasi-experimental design, and pre/post-test), one used qualitative methods (Dell et al., 2018), and four used mixed-methods designs (Butz & Stupnisky, 2017; Kiemer et al., 2018; Lozano-Jiménez et al., 2021; Zhang et al., 2020). All the qualitative and mixed-methods studies were conducted in the last six years. In the quantitative studies, three questionnaires were frequently used to assess students' motivation and perceived support: 1) the Learning Climate Questionnaire (LCQ; Black & Deci, 2000); 2) the Self-regulated Questionnaire (SRQ; Ryan & Connell, 1989); and 3) the Intrinsic Motivation Inventory (IMI; Ryan et al.,1983). The LCQ was used to assess students' perceived autonomy, competence, and relatedness support from teachers (e.g., Karl et al., 2020; Tessier et al., 2022). The SRQ and IMI were constantly used to evaluate students' intrinsic and extrinsic motivations (e.g., Brandenberger et al., 2018; Kadir et al., 2020). Table S1 presents the assessment tools used in each study.

4.5. Risk-of-bias assessment results

Fig. 6 presents the risk of bias assessment results, with ratings for each study and an overview of all the included studies. In general, the results of these interventions need to be interpreted with caution related to three criteria: 1) allocation concealment; 2) blinding of outcome assessment; 3) blinding of participants and personnel. However, the included studies did not demonstrate high risk in the areas of incomplete outcome data (2–6 weeks), random sequence generation, and selective reporting.

Most studies did not report whether they performed allocation concealment, blinding the outcome assessment, and blinding of participants and personnel. These criteria might be hard to practice in school settings, as parents and teachers have the obligation and right to know about the activities in which their children participate. Yet, there were studies clearly reporting allocation concealment. For instance, in Kaur et al.'s (2014) study, the authors stated, "Students in both the groups were kept uninformed of the experiment to control the internal validity threat of subject effect" (p. 15). Twenty-four articles did not report intervention effects after six weeks, which we interpreted as no report of long-term effects (Higgins et al., 2019). Most studies reported short-term effects instead. For random sequence generation criteria, we coded quasi-experimental studies as high risk, experimental studies that did not report the process of randomization were coded as unclear risk, and pre-post-test and qualitative studies as NA (i.e., missing data). It is understandable that there are many restrictions for implementing an experimental design in school settings. Most of the time, students enrolled in the same classroom were put in the same group. With selective reporting, one study (Blankenburg et al., 2016) was identified as high risk, since it did not report some of the variables included in the instrument they used.

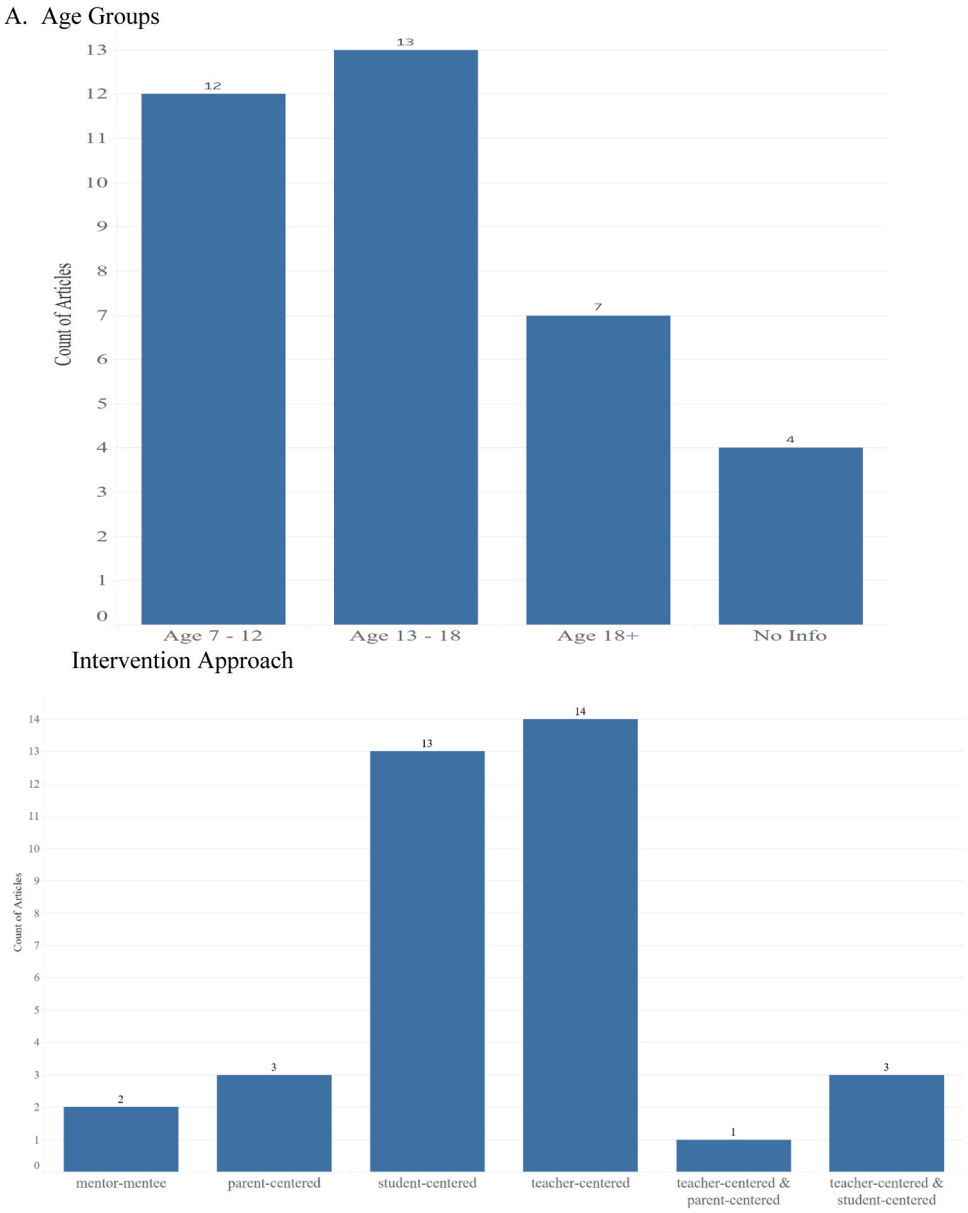

Fig. 4. Students' Age Groups and Intervention Approach.

4.6. Meta-analysis results

We used the meta-analysis to address two research questions "*Whether these interventions are effective in terms of promoting students' intrinsic motivation and supporting students' basic psychological needs?" and "What moderators played key roles?*". The analysis explored four student outcome variables (i.e., intrinsic motivation, perceived autonomy support, competence, and relatedness) due to sample size and availability of effect sizes. Even though many studies provided teacher training, these studies only involved one or two teachers (e.g., Jacob et al., 2019). Moreover, as previous research has suggested, a meta-analysis should have approximately nine effect sizes to reach a reliable conclusion and avoid type I error (Weare & Nind, 2011). Therefore, even though the articles included in the systematic review covered a wide variety of outcome variables, such as emotions or violent behaviors, only four variables had more than nine effect sizes. Moreover, an insufficient number of studies reported both pre-post differences and group differences in a manner that would allow for a robust analysis of group×time effects. This limitation necessitated our approach to separately analyze pre-post changes within intervention/experimental groups and differences between groups at post-intervention. Pre-post analysis is crucial as it tracks changes within groups over time, uncovering key benefits and effects of the intervention, distinct from control group comparisons. Meanwhile, analyzing group differences at the post-intervention time point is vital for contrasting outcomes between groups

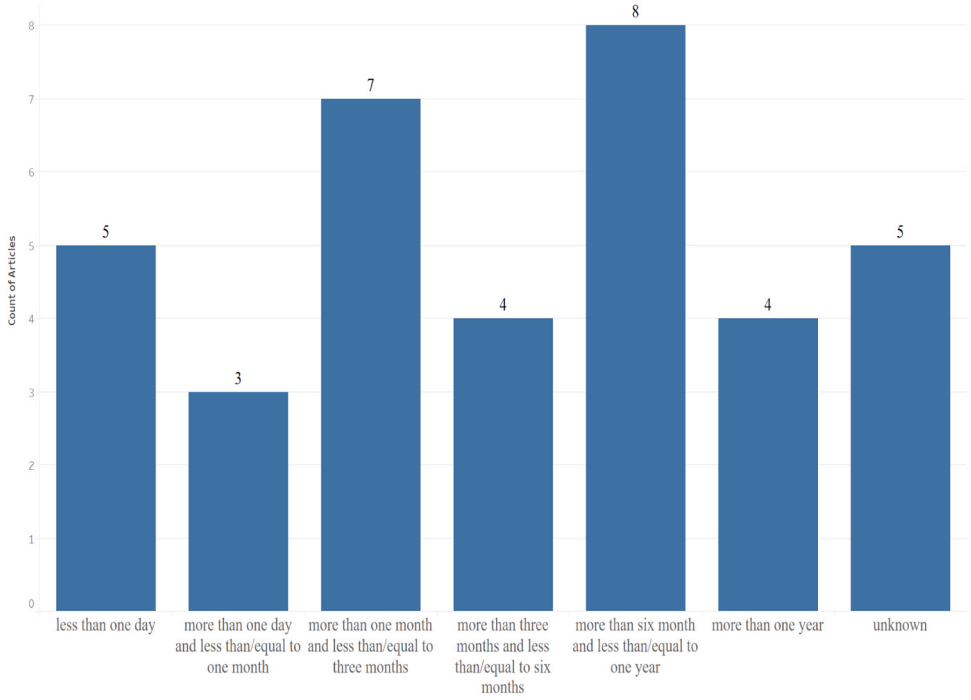

Fig. 5. Intervention duration.

at the intervention's conclusion, providing indispensable insights into the relative effectiveness of the treatment.

Effect sizes of group differences (intervention and control group), as well as pre-and post-test differences, were extracted and calculated. In total, 137 effect sizes with an overall sample size of 9433 participants reported in 31 articles were included in the meta-analysis. The data used in meta-analysis can be found in Table S2.

4.6.1. *Intrinsic motivation*

After filtering the literature, 26 effect sizes were obtained in terms of group differences in intrinsic motivation after SDT intervention, while 23 effect sizes were obtained on pre- and post-tests of the intervention group (See Table S2 and Table S3).

4.6.1.1. Group differences. In terms of *group differences*, SDT intervention yielded a significant effect on increasing students' intrinsic motivation ($g = 0.91$; 95 % CI [0.16, 1.67]; $p < 0.01$; $k = 26$). The heterogeneity test indicators ($\tau^2 = 1.35$, $I^2 = 98.46$ %, and $Q(df = 26) = 484.97$, $p < .0001$) suggest that substantial heterogeneity is present in our data. Considering the wide prediction interval (−1.57, 3.08) that extends below zero, it is prudent to temper our confidence regarding the consistently positive impact of our interventions across various contexts. There is a plausible chance that the intervention may not produce favorable outcomes in certain future conditions, and the data from our meta-analysis even suggest the possibility of slight negative effects. Conversely, significantly large effect sizes could also occur. We use outlier detection and sensitivity tests to see whether the pooled effect was biased. Studies were identified as outliers if their confidence interval did not overlap with the confidence interval of the pooled effect. Nine studies were identified as ouliers. However, the sensitivity test suggested these outliers did not substantially impact the pooled effect (No outlier: $g = 0.47$, 95 %CI [0.28, 0.67]). The findings from our sensitivity analysis suggest that our meta-analytic results are robust to the influence of potential outliers. This stability indicates that the pooled effect size is reliable and not driven by the extreme values or disproportionate influence of any specific studies.

The funnel plot (Fig. 7; Left) and Egger's test ($z = 4.15$, $p < .0001$) identified potential publication bias, so the trim-and-fill procedure was performed. The procedure identified and trimmed three studies with small effect sizes and large sampling variance (i.e., Froiland, 2010; Montero-Carretero et al., 2021; *Toshie & Osamu, 2017). The overall effect estimated by the procedure was $g = 0.58$ (95 % CI [0.26, 0.89]; $p < 0.001$; $k = 23$. We conducted a follow-up Egger's regression test and found no evidence of publication bias ($z = 1.81$, $p = 0.07$). The initial pooled effect size was $g = 0.96$, which is substantially larger than the bias-corrected effect. The bias-corrected forest plot is presented in Fig. 8A and the bias-corrected funnel plot is presented in Fig. 7 (Right).

4.6.1.2. Pre-post differences. Regarding the pre- and post-test time points, SDT interventions did not show a significant effect of time on increasing students' intrinsic motivation ($g = 0.12$; 95 % CI [0.17, 0.41]; $p > 0.05$; $k = 23$). Again, the heterogeneity test indicators ($\tau^2 = 0.14$, $I^2 = 87.46$ %, $Q(df = 22) = 102.86$, $p < .0001$, and *Prediction interval* (−0.64, 0.89)) suggested that moderate to substantial heterogeneity was present in our data. Following the same procedure stated above, we identified seven outliers, but the sensitivity test

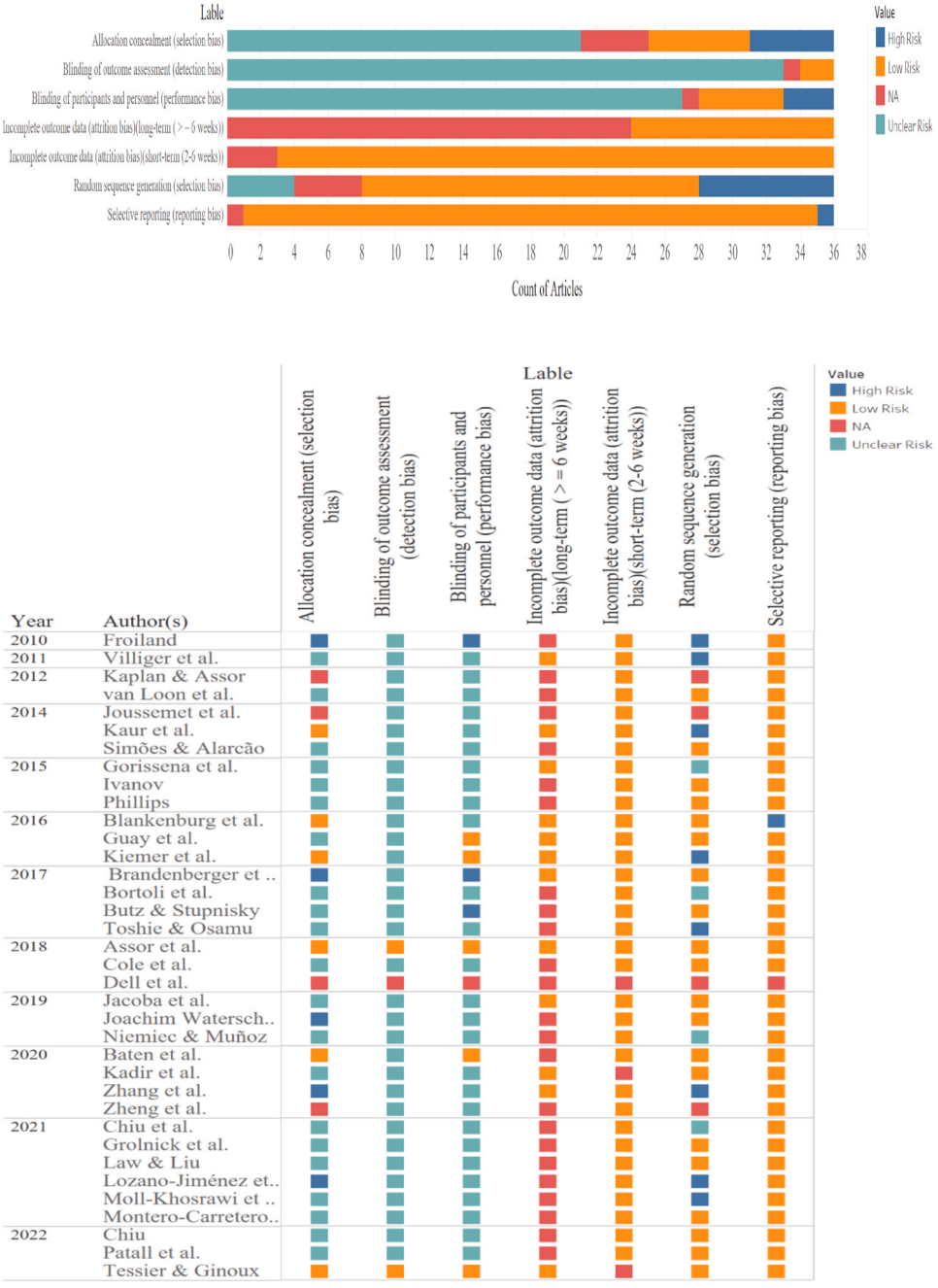

Fig. 6. Quality assessment.

suggested these outliers did not substantially bias the pooled effect (No outlier: $g = 0.01$, CI [−0.07, 0.09]).

The funnel plot (Fig. 9; Left) and Egger's test ($z = 3.09$, $p = 0.002$) identified the existence of potential publication bias, so we applied the trim-and-fill procedure as we did in our group difference analysis. This procedure identified and trimmed two studies with the smallest effect size and largest sampling variance (Ivanov, 2015; *Toshie & Osamu, 2017). The results also yielded a non-significant effect on increasing students' intrinsic motivation ($g = 0.02$; 95 % CI [−0.12, 0.15]; $p > 0.05$; $k = 21$). The bias-corrected forest plot was presented in Fig. 8B and the bias-corrected funnel plot was presented in Fig. 9 (Right).

4.6.2. Autonomy support

Twenty-two effect sizes were calculated for the group differences in perceived autonomy support, and 14 effect sizes were generated for pre- and post- differences in intervention groups.

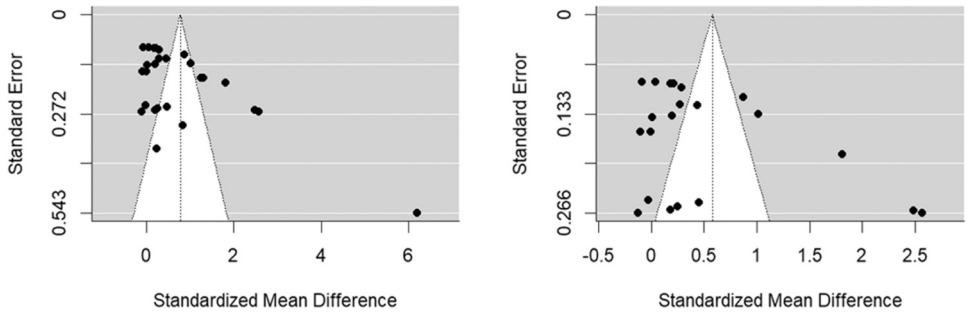

Fig. 7. Funnel Plots for Intrinsic Motivation Group Difference (Left: initial; Right: corrected for publication bias).

4.6.2.1. Group differences. For group differences, after accounting for nonindependence, the intervention group had significantly higher perceived autonomy than the control group ($g = 1.65$; 95 % CI [0.28, 3.01]; $p < 0.01$; $k = 22$). The heterogeneity test indicators ($\tau^2 = 6.09$, $I^2 = 99.42$ %, $Q(df = 21) = 1700.29$, $p < .0001$), and the *Prediction interval* (−3.57, 6.33) suggested that substantial heterogeneity was present in our data. The sensitivity analysis indicated that excluding study by Montero-Carreterowere et al., (2021) resulted in a significant change in the pooled effect size, from an original effect of 1.65 to an adjusted effect of 1.14 (95 % CI: 0.50 – 1.77, $p < 0.0001$; $k = 21$). The authors of this study noted that they used different intervention protocols, which primarily focused on bullying and had smaller sample sizes compared to the other studies in our analysis.

There was no publication bias detected by funnel plot (Fig. 10) and Egger's test (z = −0.33, p = 0.66). The forest plot is presented in Fig. 8C.

4.6.2.2. Pre-post differences. For pre- and post- differences, the intervention effect was also significant ($g = 0.63$; 95 % CI [0.06, 1.21]; $p < 0.01$; $k = 14$). The heterogeneity test indicators ($\tau^2 = 0.72$, $I^2 = 97.95$ %, $Q(df = 14) = 134.62$, $p < .0001$), and *Prediction interval* (−11.2296, 2.2155) suggest that substantial heterogeneity was present in our data. The sensitivity analysis indicated that excluding the study by Zheng et al. (2020) resulted in a significant change in the pooled effect size, from an original effect of 0.63 to an adjusted effect of 0.19 (95 % CI: 0.04 - 0.95).

The funnel plot (Figure S4) and Egger's test ($z = 3.65$, $p = .10$) indicated no publication bias. The forest plots of the included study of group and pre/post differences can be found in Fig. 8C and D.

4.6.3. Competence

4.6.3.1. Group differnces. In terms of improving students' competence, after synthesizing 17 effect sizes, we found no significant difference between intervention and control groups ($g = 0.80$; 95 % CI [−0.49, 1.65]; $p > 0.05$; $k = 17$).

The heterogeneity test indicators ($\tau^2 = 1.51$, $I^2 = 98.58$ %, $Q(df = 16) = 342.67$, $p < .0001$, and *Prediction interval* (−1.83, 3.12)) suggested that substantial heterogeneity was present in our data. The sensitivity analysis indicated that even after excluding outlier studies, the effect eize remained non-significant.

As shown in the funnel plot (Fig. 12; Left) and Egger's test ($z = 3.05$, $p = .0023$), there was potential publication bias in the result, so the trim-and-fill procedure was conducted. After trimming one study (i.e., Montero-Carretero et al., 2021), there was no publication bias detected by funnel plot (Fig. 12; Right) or Egger's test ($z = -0.04$, $p = 0.97$). The bias-corrected effect size indicated a significant group difference between intervention and control group ($g = 0.48$; 95 % CI [0.17, 0.79]; $p < 0.01$; $k = 16$).

4.6.3.2. Pre-post differnces. The pre- and post- difference in competence with nine effect sizes was significant ($g = 0.58$; 95 % CIs [0.01, 1.15]; $p < 0.05$; $k = 9$). The heterogeneity test indicators ($\tau^2 = 0.31$, $I^2 = 94.78$ %, $Q(df = 8) = 59.97$, $p < .0001$, and *Prediction interval* (−0.7386, 1.5940) suggest that substantial heterogeneity was present in our data. The sensitivity analysis indicated that after excluding one outlier (Zheng et al., 2020), the effect eize changed from medium to small ($g = 0.21$; 95 % CI: 0.1 - 0.32]; $p < 0.05$; k = 8).

Because a meta-analysis should have approximately nine effect sizes to reach a reliable conclusion and avoid Type I error, we were not able to perform the trim-and-fill procedure even though the funnel plot (Fig. 13) and Egger's test ($z = 3.60$, $p = 0.0003$) suggested the existance of potential publication bias (Weare & Nind, 2011). As a consequence, the bias-corrected forest plots of the included study of group Fig. 14A and the initial pre/post differences can be found in Fig. 14B.

4.6.4. Relatedness

4.6.4.1. Group differences. Twelve effect sizes were obtained for the group differences in students' feeling of relatedness after SDT intervention, and 10 effect sizes were generated for pre- and post-differences in intervention groups. However, the intervention effects were not significant for group differences ($g = 1.66$; 95 % CI [−0.51, 3.83]; $p > 0.05$; $k = 12$) and showed substantial heterogeneity for both groups ($\tau^2 = 8.51$, $I^2 = 99.64$ %, $Q(df = 11) = 1782.06$, $p < .0001$, and *Prediction interval* (−0.7386, 1.5940)). After removing one

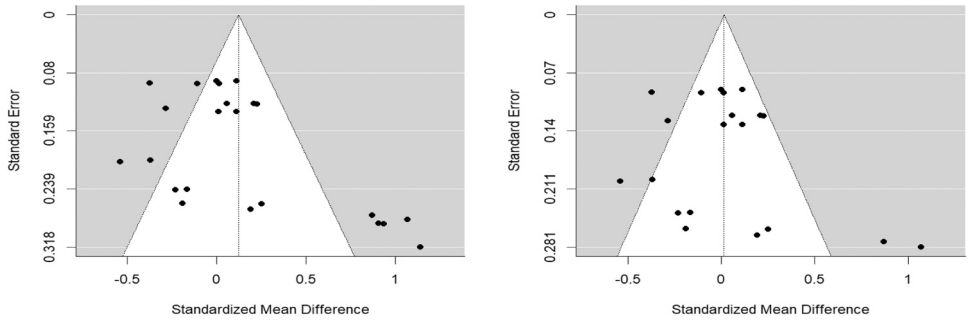

Fig. 8. Forest Plot of SDT Intervention for Intrinsic Motivation and Autonomy Suppo.

outlier (Assor et al., 2018), the effect size changed substantially from $g = 1.66$ to $g = 0.44$ (95 % CI: −0.14 – 1.02), but remained non-significant.

4.6.4.2. Pre-post differences. Pre/post differences ($g = 1.43$; 95 % CI [−0.23, 3.09]; $p > 0.05$; $k = 10$) also yielded non-significant effects, with substantial heterogeneity ($\tau^2 = 4.84$, $I^2 = 99.65$ %, $Q(df = 9) = 2028.50$, $p < .0001$, and *Prediction interval* (−3.39, 5.65)). However, removing one outlier (Assor et al., 2018) changed the effect size from 1.43 to 0.34 (95 % CI: −0.06 – 0.96).

There was no publication bias identified for either group differences results (see Fig. 15; Egger's test: $z = 0.85$, $p = 0.40$) or pre/post results (see Fig. 16; Egger's test; $z = 0.61$, $p = 0.54$). Forest plots of the included study of group and pre/post differences can be found in Fig. 14C and D.

In summary, Self-Determination Theory (SDT) interventions consistently support students' need for autonomy and competence across both experimental/quasi-experimental and pre-post study designs. These interventions also demonstrate a partially significant effect in enhancing students' intrinsic motivation within experimental/quasi-experimental design. However, they do not show a significant pooled effect in meeting students' needs for relatedness. It is important to note that despite the substantial heterogeneity observed in our dataset, we employed a random effects model to account for this variability. This decision was made a-priori, based on the recommendation by Koricheva et al. (2013), to use a random effects approach rather than a fixed effects model, thus acknowledging and incorporating the diversity of effects observed across studies.

4.7. Moderator analysis

The results of the moderator analysis indicated that the duration of the intervention, student's age, gender, and geographic origin should be considered in future SDT interventions for promoting participants' autonomy support, competence, relatedness, and intrinsic motivation. The results of the moderator analysis were reported in Table S3 and S4.

4.7.1. Intervention approaches and study design

The results showed that the moderator effects of the intervention approaches were not significant for autonomy support, competence, relatedness, and intrinsic motivation regardless of group difference and pre- and post-differences. However, our analytic method required a full-rank matrix to estimate effects (Currie, 2020); accordingly, we did not have sufficient data to estimate a moderator effect for study design.

4.7.2. Duration of the intervention

Our findings showed that the moderator effects of the duration of the intervention were inconsistent across studies. In terms of group differences, the interventions that ranged from six months to one year were most effective for autonomy support ($b = 11.23$, 95 % CIs [7.90, 14.56]; $p < 0.000$) and competence ($b = 8.69$, 95 % CIs [7.25, 10.14]; $p < 0.000$). In addition, the interventions that ranged from one day to one month had the best effects for relatedness ($b = 8.56$, 95 % CIs [8.21, 8.91]; $p < 0.000$). For the pre- and post-differences, interventions that lasted less than one day were most effective for autonomy support and relatedness. The interventions that lasted from one day to one month worked most effectively for intrinsic motivation ($b = .67$, 95 % CIs [.11, 1.24]; $p < .02$).

4.7.3. Students' age

For the group differences, the results indicated that the interventions for adolescents who were between 13 and 18 years old were effective in improving autonomy support ($b = 12.13$, 95 % CIs [9.35, 14.91]; $p < 0.000$) and competence ($b = 22.55$, 95 % CIs [19.10, 25.99]; $p < 0.000$). The interventions for children who were between seven to twelve were most effective for relatedness. However, there was no difference across ages for improving intrinsic motivation. In terms of the pre- and post-differences, the interventions for participants who were between 13 and 18 years old were the most effective for autonomy support; the interventions for children who were between seven and 12 years old were better than other subgroups for competence. In addition, the interventions for participants who were older than 18 years were most effective in improving relatedness ($b = 5.39$, 95 % CIs [5.04, 5.74]; $p < 0.000$). However,

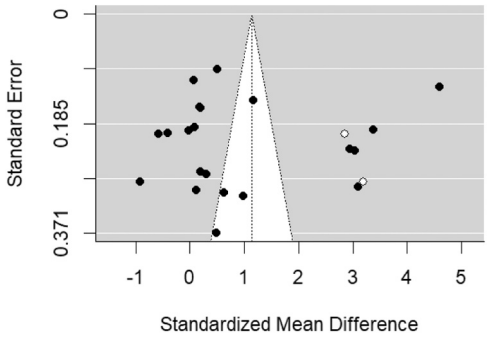

Fig. 9. Funnel Plots for Intrinsic Motivation Pre-Post Difference (Left: initial; Right: corrected for publication bias).

there was no difference across ages for improving intrinsic motivation.

4.7.4. Students' gender

The findings indicated that the interventions for improving participants autonomy support (b = 4.75, 95 % CIs [2.78, 6.72]; $p < 0.001$) and competence ($b = 4.44$, 95 % CIs [3.67, 5.20]; $p < 0.001$) were more effective for female participants compared to male participants in terms of group differences. No results could be generated for relatedness due to the small sample size and missing gender data in some studies.

4.7.5. Students' geographic origin

The moderator effects of students' geographic origin were not consistent. For group differences, the interventions conducted in Europe for improving students' autonomy support ($b = 8.34$, 95 % CIs [6.18, 10.51]; $p < 0.000$) and competence ($b = 17.64$, 95 % CIs [14.93, 20.35]; $p < 0.001$) were most effective, but the interventions organized in Asia for improving students' relatedness were more effective than those in other continents. There was no difference among continents for improving intrinsic motivation. Regarding the pre- and post-differences, the interventions for promoting students' autonomy support and relatedness in Asia and Europe were the most effective, and the interventions for improving student's competence in Asia were most effective. There was no difference across continents in improving intrinsic motivation.

5. Discussion

The aim of this systematic review and meta-analysis was to provide a comprehensive description of research on Self-determination Theory (SDT) based interventions in education. With a synthesis of 36 interventions, we aimed to summarize the characteristics of SDT interventions and determine whether these interventions were effective in promoting students' autonomous motivation and enhancing students' autonomy, competence, and relatedness through meta-analysis. We also attempted to identify why some interventions appeared to be more effective than others. In this section, we discuss our findings, followed by suggestions for future empirical research and practice.

5.1. Systematic review of SDT Interventions

In reviewing the geographic location of the included studies, we discovered that the majority of SDT interventions were conducted in developed countries in North America and Europe. Participants in these studies were predominantly white. There were also a significant number of studies conducted in Asian countries. These interventions have five major approaches: teacher-centered, student-centered, parent-centered, mentor-mentee, and combined approach. We discuss these approaches below.

5.1.1. Teacher-centered approach

Teacher-centered SDT intervention was the most popular approach that we identified in our review. Fifteen articles used SDT-informed teacher training and professional development to help teachers support their students' three basic psychological needs, promote autonomous motivation, and decrease controlled motivation. Among these interventions, autonomy-supportive teaching strategies were adopted most frequently, whereas fewer articles mentioned competence and relatedness-supportive strategies. Specifically, eight articles primarily focused on autonomy-supportive strategies training, two articles involved both autonomy and competence-supportive strategies, and seven articles covered all three basic psychological needs. We summarized the autonomy-supportive, competence-supportive, and relatedness-supportive strategies and operationalization in articles that provided comprehensive descriptions in Table S5. Many autonomy-supportive strategies were generated based on Reeve's studies (e.g.,Cheon et al., 2018; Reeve, 1998; Reeve & Jang, 2006), while competence and relatedness-supportive strategies were developed based on Deci and Ryan's SDT work (e.g., Ryan & Deci, 2008, 2017). Instead of focusing on academic outcomes, one articles provide teacher training to address violence and bullying among students.

These teacher training and professional development programs shared similar characteristics. First, all of the training programs

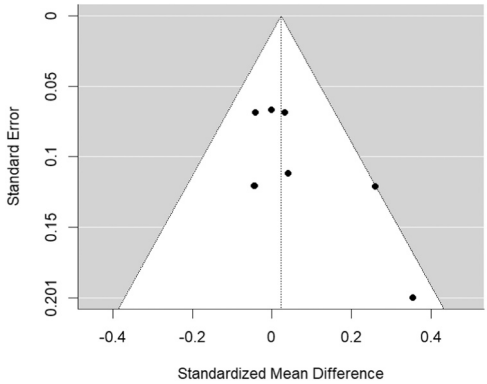

Fig. 10. Funnel Plots for Autonomy Support Group Difference (Left: initial; Right: corrected for publication bias).

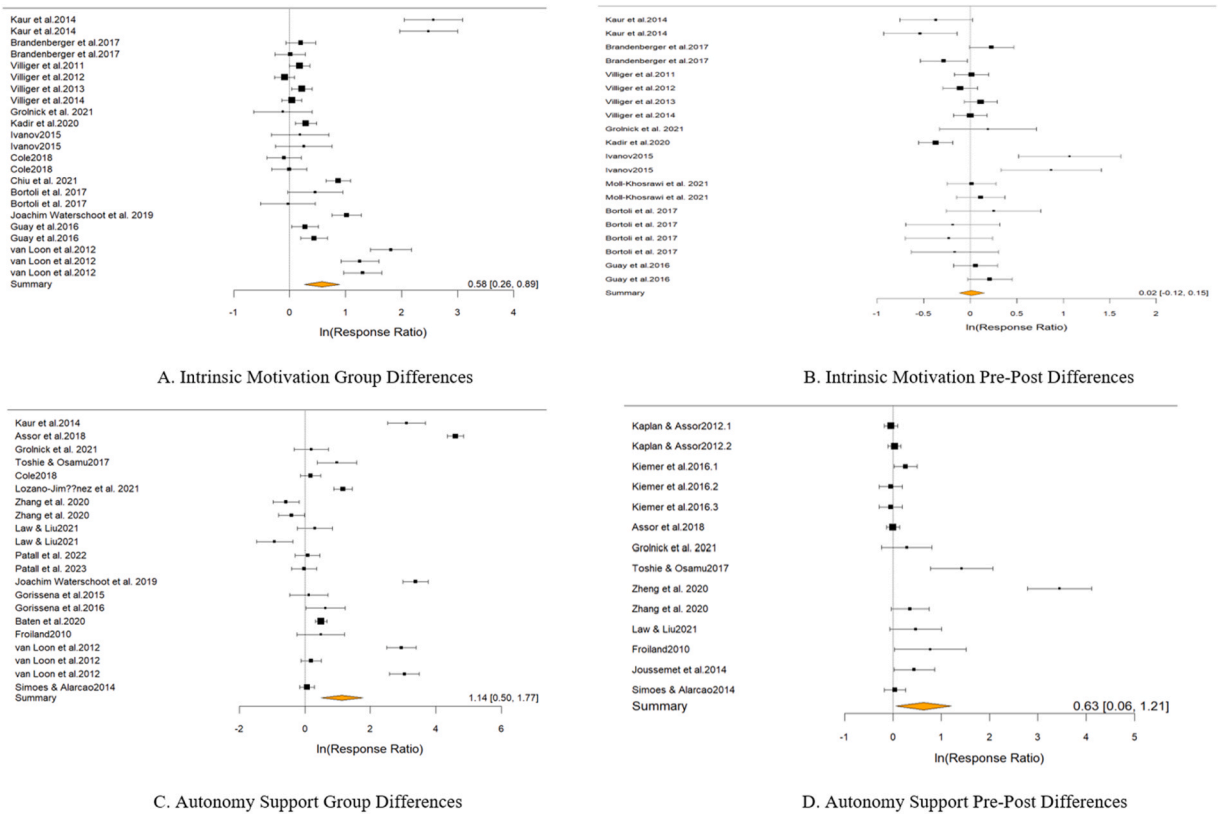

Fig. 11. Funnel plots for autonomy support pre/post difference.

have informational sessions including SDT, three basic psychological needs, and different strategies to support student needs (e.g., Collins, 2000; Chiu et al., 2021). Second, most of the training programs have discussion components in which teachers were invited to share their own experiences (e.g., Niemiec & Muñoz , 2019). Third, another popular approach is roleplay, which helps teachers have a better understanding of students' perspectives (e.g., Kadir et al., 2020; Zhang et al., 2020). Fourth, many training programs used video recordings from participating teachers as teaching materials or evaluation tools (Kiemer et al., 2018). Fifth, case study and video analysis were common approaches (Guay et al., 2016; Tessier et al., 2022). Sixth, intervention programs provided teachers with supporting materials, such as websites, booklets, and detailed course plan protocols (e.g., Niemiec & Muñoz et al., 2019). Seventh, reviews of content from the previous training session contents were common in training procedures (e.g., Collins, 2000).

5.1.2. Student-centered approach

In total, 13 articles took a student-centered approach, within which five interventions targeted university students, four targeted elementary school students, and two targeted middle schools. Unlike the teacher-centered approach, the student-centered approach

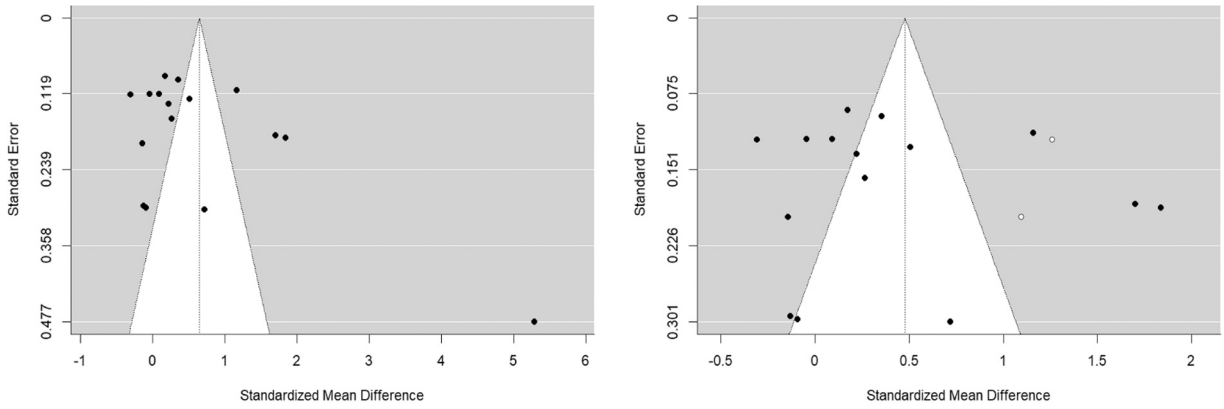

Fig. 12. Funnel plots for competence support group difference (Left: initial; Right: corrected for publication bias).

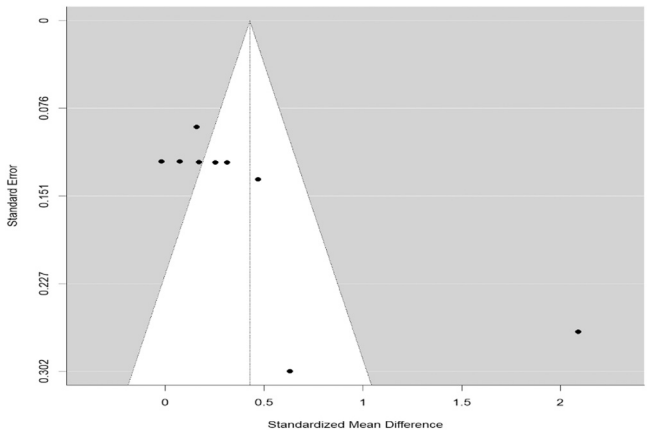

Fig. 13. Funnel plots for competence support pre/post difference.

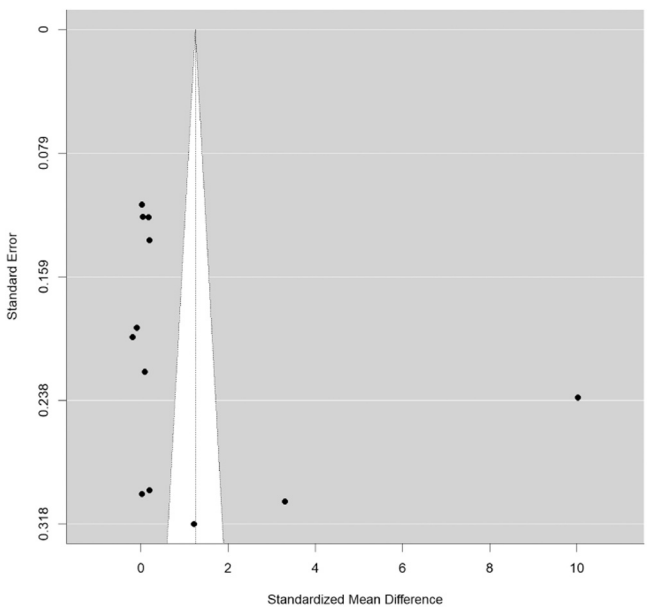

Fig. 14. Forest plot of SDT intervention for competence and relatedness support.

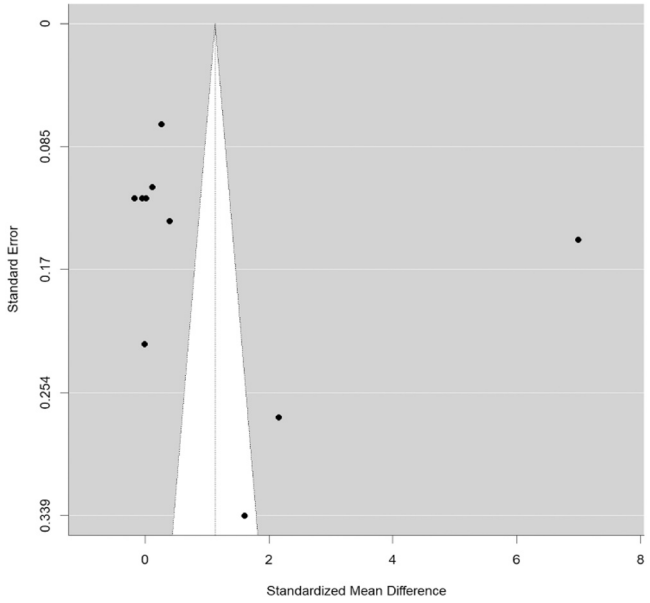

Fig. 15. Funnel plots for relatedness support group difference.

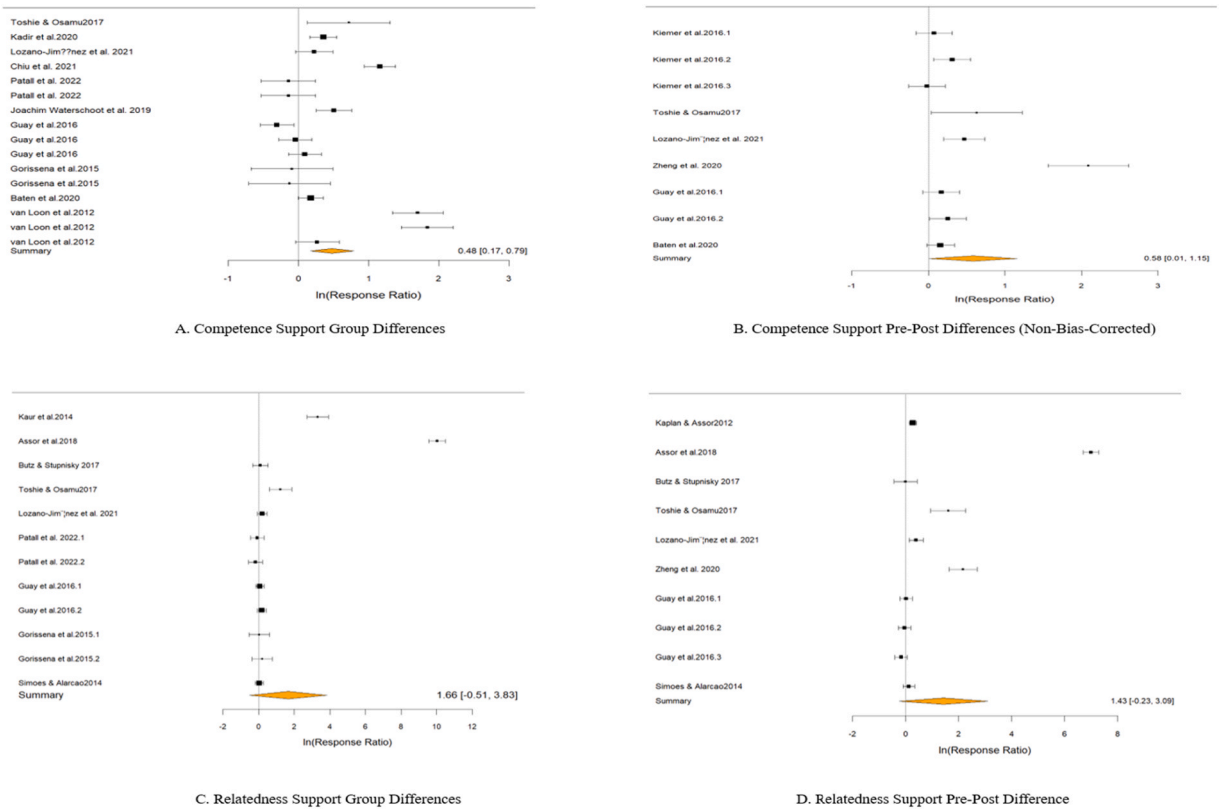

Fig. 16. Funnel plots for relatedness support pre/post difference.

had large variability in intervention design.

For university students, the interventions attempted to improve students' relatedness using online discussion (Butz & Stupnisky, 2017), academic performance (Cole, Bergin, & Summers, 2018; *Toshie & Osamu, 2017), autonomous motivation through bedside-teaching (Moll-Khosrawi et al., 2021), learning and health literacy via need-satisfying intervention (Zheng et al., 2020),

international students' need-satisfaction and adjustment (Law & Liu, 2021), and agentic mindset by an agentic orientation intervention (Patall et al., 2022). All studies reported that their interventions achieved or partially achieved the study goals. Interestingly, the lottery-based rewards only successfully promoted male students' academic performance (Cole et al., 2018). Moreover, bedside-teaching, which involves the perioperative care of the patient with an anesthesiologist, showed conflicting results: decreased external (controlled) motivation and identified (autonomous) motivation at the same time (Moll-Khosrawi et al., 2021). The authors suggested that providing more supervision for students could prevent the unintended decrease of identified motivation. By acknowledging that every student has the basic psychological need for autonomy, Patall and her colleagues (2022) presented one of the first agentic orientation interventions that improve university students' agentic mindset, and could also influence students' engagement, need satisfaction, personal interest, and persistence.

We identified two interventions targeted at middle school students, each of these focus on different aspects. One of the studies used science competitions to satisfy students' basic psychological needs to promote students' interests and passion for science (Blankenburg et al., 2016). The competition had adequate task difficulties to satisfy the need for competence, options for a range of topics and activities to satisfy the need for autonomy, and play/work in teams to satisfy the need for relatedness. The other middle school students SDT intervention studies used reflective journals/diaries as the intervention method: one dissertation aimed at promoting life satisfaction, effort, attitude, and prosocial behavior (Phillips, 2015). However, this intervention appeared to be ineffective in its area of focus.

For elementary students, all the interventions were targeted at changing students' academic motivation by altering the environment or teaching techniques. Specifically, the interventions aimed at promoting these students' intrinsic motivation using a choice provision condition (Waterschoot et al., 2019), decreasing students' controlled motivation via the autonomy-supported hypermedia environment (Gorissen et al., 2015), dampening the negative effect of difficult math tasks using autonomy-supportive instruction (Baten et al., 2020), and improving students' intrinsic motivation and learning outcomes through an autonomy supportive and structured digital learning task (Van Loon et al., 2012). All four studies allocated students to two or more groups (e.g., autonomy-supported, no autonomy-support, or controlling instruction), and reached the same conclusion that autonomy support, assisted by creative instruction methods (e.g., digital learning, hypermedia, comic book, painting activity) could help students in various ways, for instance, overcome difficult math problems (Baten et al., 2020), promote intrinsic motivation and learning outcomes (Gorissen et al., 2015; Van Loon et al., 2012; Waterschoot et al., 2019).

5.1.3. Parent-centered approach

Three articles took a parent-centered approach (Froiland, 2011; Grolnick et al., 2021; Joussemet et al., 2014). All three studies provided training programs to foster optimal parenting and shared several other characteristics. First, each of these studies introduced autonomy-supportive strategies, such as taking the child's perspectives, using non-controlling language, and listening with warmth and attention. Second, through discussion, examples, and role play, these interventions asked parents to take students' perspectives and provided educational materials (e.g., worksheets and booklets). Third, researchers tried to satisfy parents' needs and expectations to make sure parents were actively participating in the programs and wanting to apply these newly learned parenting strategies. Fourth, all studies reported a positive change in parents and their children in terms of autonomy, positive affect, and fewer behavioral problems. There were also some differences among these studies. In Grolnick et al.'s (2021) study, the intervention was performed by a licensed clinical psychologist and had two sessions (1.5 h each session). In Froiland's (2010) study, there were seven sessions (30 min each session) led by a consultant. The intervention introduced 19 *Inspirational Motivational Styles* techniques with educational-related scenarios. Joussemet et al. (2014), reported eight intervention sessions led by trained graduate students in psychology. This study provided a clear table of 30 SDT-informed skills and parenting examples.

5.1.4. Mentor-mentee approach

Two articles took a mentor-mentee approach. Using qualitative methods, Dell et al. (2018) successfully promoted women's retention rates in the engineering program. Simões & Alarcão (2014) also took a mentor-mentee approach, but with a larger general population to promote teenagers' (9–16 years old) well-being. However, the results showed no significant differences between the mentored and non-mentored students regarding personal well-being and social well-being. The reason for the different results might be that the mentor-mentee approach works more efficiently with a targeted group (e.g., an underrepresented group) with special needs and a group of mentors with an abundant experience in the field that these mentees are interested in. The last study (Simões & Alarcão, 2014) used students' teachers as mentors but did not specify how many mentees these mentors were serving. If the mentors were overwhelmed by the obligation, they might not be able to connect and support the mentees well.

5.1.5. Combined approach

Four articles took a combined approach: three teacher-student interventions, and one teacher-student-parent intervention. Villiger et al. (2012) was the only study that involved teachers, parents, and students in the intervention to enhance Swiss fourth graders' reading motivation and comprehension. Teachers received six hours of training on new teaching methods that supported students' three basic psychological needs. Parents were trained on homework-assistant strategies that embedded SDT concepts. Students also participated in the three hours of parent training sessions to enable a semi-authentic homework situation. The intervention boosted reading enjoyment and reading curiosity, but not reading comprehension.

5.2. Meta-analysis of SDT interventions

The present meta-analysis had two purposes. First, it aimed to unravel whether the SDT interventions were effective in promoting students' intrinsic motivation and satisfying students' three basic psychological needs (autonomy, competence, and relatedness). We analyzed both pre-post-test differences and intervention-control group differences. Second, the meta-analysis investigated relevant moderators that made the included interventions more or less effective.

5.2.1. Intervention effectiveness

The results from the meta-analysis showed that SDT intervention programs can impact students' intrinsic motivation with a medium to large effect size of 0.58. Students' intrinsic motivation in intervention groups was significantly higher than students in control groups. However, the pre-post-test differences within the intervention group did not show an overall significant effect of the intervention. In terms of autonomy support, SDT interventions were effective and showed a large effect (1.14) for group difference and a small effect for pre-post-test difference (0.19). Such results mean these interventions successfully supported students' autonomy. For competence, only the pre-post difference was significant and had a small effect (0.21). However, intervention effects for relatedness were not significant. Overall, the interventions were successful in helping students feel more autonomy-supported, and partially successful in terms of intrinsic motivation and competence, while not effective in promoting students' feeling of relatedness. It is understandable that autonomy support has the most well-established practical guidelines (e.g., Reeve, 1998; Reeve & Jang, 2006), while the other two psychological needs, competence and relatedness, were not systematically studied and emphasized in these interventions. Moreover, students may have been more intrinsically motivated if their three basic psychological needs were all satisfied. If students' needs for competence and relatedness were not successfully satisfied, then the intervention effects on intrinsic motivation could be weakened.

5.2.2. Moderators

As the meta-analysis has eight categories, the results for each moderator were inconsistent but showed some useful trends. In general, we did not identify significant differences between intervention approaches. Moreover, interventions that lasted between one day to one month were most effective in promoting students' intrinsic motivation and relatedness needs. In addition, SDT interventions were most efficient for late childhood and adolescent participants (7–18 years old). This result demonstrated that SDT interventions addressing the developmental decline of participants' intrinsic motivation were most effective. Moreover, SDT interventions were more effective for female participants in terms of satisfying autonomy and competence needs. Finally, SDT interventions were most effective in Europe and Asia. These results might be due to the more-frequent research in these two continents compared to other parts of the world. Cultural factors in Europe and Asia might also play a role in the success of these interventions. For instance, certain aspects of SDT, such as the emphasis on autonomy and relatedness, might align well with educational practices and cultural values in these regions, thereby enhancing the effectiveness of the interventions (Kaur & Noman, 2020). However, further investigations are needed to explore and justify this phenomenon.

5.3. Research recommendations and future directions

5.3.1. Research recommendations

We suggest that future SDT interventions consider the aspects stated below in terms of research design and practical implementation. First, according to risk-of-bias assessment (Fig. 7), few studies clearly stated that they blinded participants: It was unclear whether the participants were informed about the intentions of the interventions presented to them. Most of the successful interventions did not let participants know that they were involved in an intervention or the purpose of the intervention (Robinson et al., 2013; Yeager & Walton, 2011). Second, future SDT interventions should avoid using only one type of assessment, such as a self-report survey or interview. Self-report data can be biased and provide limited insight into behavior. Accordingly, results may not be accurate (Semmer et al., 2003). Moreover, self-report data only demonstrates change in participant mindsets, but many SDT interventions also aim at changing teachers', parents', and students' day-to-day behaviors, so adding behavioral assessments is highly recommended (Dang et al., 2020; Patall et al., 2022). There are many available behavior codebooks that future SDT interventions could adopt (e.g., Collins, 2000; Reeve et al., 2004; Tessier et al., 2022).

Third, researchers should be aware that there are specific interventions that might not work for different genders, cultures, and subjects equally (Wentzel & Wigfield, 2007). For instance, the intervention designed by Cole et al. (2018) was only effective for male participants. Furthermore, some basic psychological needs strategies were effective for English classes, but may be less effective for other subject areas, such as mathematics (*Toshie & Osamu, 2017). Therefore, involving an expert in the targeted subject to design the intervention content is necessary. Most current interventions completely adopted the need satisfaction strategies developed in previous research without a clear justification on what and why such strategies will work in their specific context. Fourth, surprisingly, only nine articles mentioned intervention fidelity control, with only four articles including a detailed discussion about fidelity (Henry et al., 2020; Kadir et al., 2020; Lozano-Jiménez et al., 2021; Nunn, 2018). It is necessary to provide readers with information, such as intervention design, intervention delivery, intervention receipt, and intervention enactment, so they understand that the intervention is implemented as intended and any deviations occurred during the intervention implementation.

5.3.2. Future directions

On top of these aspects, future research could expand on the following five directions. First, the available competence and

relatedness needs-support strategies are less effective compared to autonomous need support strategies. More competence and relatedness needs-support interventions should be developed and tested. Furthermore, some of the strategies in current literature were not used appropriately. For instance, some researchers used "providing clear course structure" as an autonomy support strategy, but others claimed that it is a competence support strategy. One recent study provided a clear classification of three basic psychological need-supporting strategies that can guide future intervention research (Ahmadi et al., 2023).

Second, SDT could enhance the effect of other theory-driven interventions. Previous interventions discovered that combining SDT enhanced the effects of design thinking and multimedia instructional interventions (Chiu et al., 2021; Gorissen et al., 2015). Future teacher training could introduce teaching strategies for basic psychological needs along with their targeted training content, such as promoting higher-order thinking, to improve the training efficiency. Third, more than one-third of the studies in our review claimed that their research suffered from small sample size, lack of diverse samples, and single-center design. Future researchers could expand on these studies to provide stronger evidence and better generalizability of the available intervention. Fourth, due to the nature of this type of research, all the teachers, students, and parents participated in these interventions voluntarily, which means, in most of the scenario, they were willing to change and learn new things, especially for teacher training interventions. However, current research did not specifically consider the role of participants' characteristics, such as personality and learning competencies (Jacob et al., 2019). Previous research showed that enthusiastic teachers automatically satisfy students' psychological needs better than less enthusiastic teachers (Kunter et al., 2008). However, what about those less enthusiastic teachers who do not want to participate in the intervention?

The question above leads to our final point: the sustainability and replication of SDT interventions. It is always challenging to operationalize a theory and make the intervention effect sustainable (Lazowski & Hulleman, 2016). Most of the included research (24 articles) did not assess the long-term effects of the intervention and did not involve participants in the development process. In the future, researchers can consider monitoring long-term effects of SDT interventions and involving participants in the development process; these efforts may make the intervention more context-specific and participant-centered. To make the intervention effects more sustainable, researchers could involve the community, including school districts and parents. When the community is invested in the outcome of an intervention, they are more likely to work to maintain the changes that have been achieved (Margolis et al., 2001). For example, researchers should encourage community members to take ownership of the program and to take an active role in its implementation and ongoing maintenance. Additionally, we need to invest in building the capacity of individuals (e.g., teachers and parents) and schools to ensure that they have the skills, resources, and knowledge necessary to sustain the changes that have been achieved through the intervention. Potentially, less enthusiastic teachers will join SDT training if their peers advocate for it. Partnerships between schools and higher education researchers can help to ensure that an intervention is sustained over time (Howie et al., 2014). Such partnership is necessary, as most of the current interventions lack continuous monitoring and evaluation. It is critical to ensure that the intervention achieves its desired outcomes and that changes are sustainable over time. The results can also be used to make adjustments and improvements to the intervention as needed. Researchers can also provide ongoing support and training to ensure that the individuals and organizations involved in the intervention have the necessary skills and knowledge to maintain its impact over time. Tools such as websites, such as those designed in Reeve et al.'s (2004) intervention, or the newly developed self-study smartphone App, *ACE self-study*, could assist in maintaining the sustainability of the intervention as well.

5.4. Limitations

The current systematic review and meta-analysis has several limitations. First, we did not conduct grey literature and forward citing searches, so it is possible that research published in these outlets might be missing from the current review. Second, we did not conduct a systematic review and meta-analysis of teachers, parents, and mentors' outcome due to the focus of our current study. In addition, more than a third of the articles included in our review did not include details about participant race and ethnicity, so relevant subgroup analyses could not be conducted. It was challenging to summarize students' race and socioeconomic status in the included studies because few studies reported such information. Studies conducted in the US discussed participants' race more carefully compared to others. Third, the results of meta-analysis and moderator analysis should be interpreted carefully, as the number of studies included in some subgroups were small (e.g., competence, $k = 6$; relatedness, $k = 8$). For these subgroups, we recommend that readers interpret the qualitative review and meta-analysis results together. The fourth limitation concerns the assessment tools used in the intervention studies. The SDT interventions that we reviewed used various types of assessment tools and measured outcomes differently. For instance, some studies measured intrinsic motivation using effort, some using interests, and others using both. Some studies measured all kinds of motivation and regulation styles (i.e., amotivation, lack of motivation, introjected motivation, identified motivation, integrated motivation, and intrinsic motivation), while some only measured intrinsic motivation. To avoid confusion, we listed all of the measurement tools that the included studies used in Table S1.

5.5. Conclusions

Research on SDT interventions has documented their effectiveness and is a topic of growing interest. This proposed research aims to provide a comprehensive profile of SDT-based education interventions to assist future researchers in developing or replicating such interventions in a subject, age, culture, and diversity-sensitive manner. Also, nine practical directions and recommendations for research and practice advice were provided to guide future SDT intervention design.

Conflicts of interest/Competing interests

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Code availability

The authors will share the code on the Center of Open Science Website.

Ethics approval

Not Applicable.

Consent to participate

Not Applicable.

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CRediT authorship contribution statement

Yurou Wang: Writing – review & editing, Writing – original draft, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Shengnan Wang:** Data curation. **Hui Wang:** Methodology, Data curation. **Christopher Gill:** Data curation. **Stefanie A. Wind:** Writing – review & editing, Methodology, Data curation.

Data availability

The authors do not have permission to share data.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.lmot.2024.102015.

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References marked with an asterisk (*) indicate studies included in the research synthesis.; References marked with two asterisk (**) indicate studies included in the meta-analysis.

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