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A Scoping Review of Flipped Classrooms in K-12 Science Education: Implications and Recommendations for Future Research and Practice

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Abstract

The flipped classroom pedagogy has gained prominence in various educational contexts by reorganising the lectures of content knowledge via instructional videos, and squeezing in more time for class activities. Although there have been numerous studies of the design, implementation, and evaluation of the flipped approach, their outcomes varied in different disciplines. A pioneering scoping review was conducted to examine and illustrate existing research in K-12 science education. This study identified 358 peer-reviewed articles 15 of which were selected for analysis using a rigorously established five-stage scoping framework. The results indicated an overall positive impact from flipped classrooms, on motivation, engagement, and attitude, but there were mixed findings regarding academic performance. As in other flipped learning reviews, several student-related, faculty-related, and operation-related challenges were also identified in K-12 science education. To explore the current research gaps for flipping science classes, the identified studies were further analysed using a refined Spector's six pillars, and the synergetic incorporation of self-regulated and technology-enhanced predict-observe-explain (POE) strategies into flipped classrooms in K-12 science education was proposed.

Keywords: flipped classroom, scoping review, K-12, science education, technology-enhanced learning

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Introduction

Over the past decade, the flipped classroom (FC) approach has been widely incorporated in courses and educational contexts around the world (Zainuddin, Haruna, Li, Zhang, & Chu, 2019). Research using this approach has also been proliferating due to the notion of freeing up more class time for student-centred learning activities (Bishop & Verleger, 2013). Investigations into the efficiency of the FC were found in a wide range of disciplines, varying from elementary school mathematics classes (Lai & Hwang, 2016) to university-level multimedia courses (Enfield, 2013). There were also positive and neutral effects on student learning in FCs in the categories of (a) learning achievement. which includes academic performance and higher-order thinking skills such as problem-solving and critical skills (e.g., González-Gómez, Jeong, Rodríguez, & Cañada-Cañada, 2016); (b) engagement and motivation (e.g., Chen, Wang, Kinshuk, & Chen, 2014); (c) satisfaction and attitude (e.g., Enfield, 2013); (d) social interaction (e.g., Lee, 2018); as well as (e) self-efficacy (e.g., Sun, Xie, & Anderman, 2018).

Existing research findings derived from subjects other than science may not be entirely suitable to guide the design and deployment of FCs in K-12 science education. Compared to other K-12 subjects, K-12 science education emphasises not only content knowledge, which supports students in explaining phenomena scientifically, but also procedural and epistemic knowledge that helps students to design scientific enquiries, and interpret data (OECD, 2019). Curricula in many countries (e.g., USA , National Research Council, 1996; England, Department for Education, 2011; Hong Kong, Curriculum Development Council, 2017) also emphasise the promotion of scientific literacy, which involves not only scientific knowledge (knowledge of and about science), but also the use of knowledge and process skills to tackle issues and problems related to a student's daily situation in a K-12 science context (Vieira & Tenreiro-Vieira, 2016). Consequently, existing findings about FC efficacy on the impact of student performance without a thoughtful evaluation of the aforementioned aspects may not be applicable and insightful for flipping a K-12 science class.

Different science educators and researchers also have different perceptions and research findings regarding the impacts of FC. For instance, Bergmann and Sams (2012) were pioneers in constructing an authentic classroom called the Flipped Mastery Classroom for the teaching of high school chemistry science 2008, with much positive feedback. Jensen, Kummer, and Godoy (2015), however, believed that an improvement in undergraduate biology performance was due to active learning strategies rather than flipping the class. Such discrepancies indicate the need for a more in-depth examination of existing literature to identify the types of available evidence that specify the FC in the K-12 science discipline (Munn et al., 2018).

The justification for the theoretical foundation of FC in K-12 science education is inadequate, despite the proliferation of its implementation. Several FC studies were grounded in a well-defined theoretical (e.g., self-determination theory, Sergis, Sampson, & Pelliccione, 2018; cognitive load theory, Bhagat, Chang, & Chang, 2016) or pedagogical frameworks (e.g., 5-E instructional model, Jensen et al., 2015; peer instruction model, Faulkner & Green, 2015) in different disciplines. The significance and implications of these frameworks for the design and implementation of FC in K-12 science education have not yet been identified and illustrated, however. Such under-evaluation and under-theorisation (Abeysekera & Dawson, 2015) may restrict science educators from unleashing the potential of FCs tailored for the teaching and learning of science at K-12 level.

Last but not least, more and more meta-studies and systematic reviews of the existing literature have been conducted to render a clear picture of how educators have designed and implemented the FC approach (Abeysekera & Dawson, 2015), however, most of the existing systematic reviews were restricted to higher education (e.g., Bishop & Verleger, 2013; O'Flaherty & Phillips, 2015). Some were also limited to disciplines that were only offered at university, such as health professions education (e.g., Hew & Lo, 2018), medical courses (e.g., Lin & Hwang, 2019), nurse education (e.g., Bernard, 2015; Betihavas, Bridgman, Kornhaber, & Cross, 2016), and computer science education (e.g., Giannakos, Krogstie, & Chrisochoides, 2014). In some meta-analyses of FC focusing on broader educational levels, very few studies were identified in K-12 science education (e.g., van Alten, Phielix, Janssen, & Kester, 2019, n = 4; Zhang, 2018, n = 6). Finally, there was only one scoping study (Lo & Hew, 2017) exclusively targeted at FC studies at K-12 education, but most of the studies examined were confined to mathematics education. Systematic reviews, meta-analyses and scoping reviews specifying FC in K-12 science education were also lacking at the time of writing.

This scoping review was therefore conducted to primarily explore (a) how science teachers design their FCs in terms of their theoretical and pedagogical considerations, (b) the efficacy of flipped interventions on student learning in science, and (c) the challenges of flipping science courses in a K-12 context. The evidence identified and mapped in this review could therefore act as a precursor of a more precise systematic review or meta-analysis in the future (Munn et al., 2018).

Methodology

A rigorous and reliable five-stage framework (Arksey & O'Malley, 2005) was adopted in this scoping review of FC in K-12 science education. The five stages of Arksey and O'Malley's (2005) framework include: (1) identifying the initial research questions; (2) identifying relevant studies; (3) selecting studies; (4) charting the data; and (5) collating, summarising, and reporting the results. Thoughtful data coding methods and procedures were also established to ensure the validity of the data extraction and analysis for the selected studies in this scoping review.

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(1) Identifying the initial research questions

This review was conducted to address the following initial research questions about FCs in K-12 science education:

(a) How are FCs designed in terms of in-class and out-of-class activities, as well as the grounded frameworks in K-12 science education?

(b) What are the impacts of FC interventions on student learning outcomes in K-12 science education?

(c) What challenges have teachers and students been facing in the teaching and learning of science with the FC approach in K-12 science education?

(2) Identifying relevant studies

Seven electronic databases were searched to identify relevant studies as comprehensively as possible (Lo & Hew, 2017, O'Flaherty & Phillips, 2015). They included (a) Academic Search Ultimate, (a) ERIC, (c) Education Research Complete, (d) Education Full Text (H.W. Wilson), (e) Teacher Reference Center, (f) the British Education Index, and (g) Library, Information Science & Technology Abstracts. In addition, the reference lists of identified articles, as suggested by O'Flaherty and Phillips (2015) and Lo (2017), were also searched to find any other primary sources of related research.

The following key terms were used in this search: (flip* OR invert*) AND (class* OR learn*) AND (science OR physics OR chemistry OR biology OR STEM) AND (K12 OR K-12 OR primary OR elementary OR secondary OR high school OR middle school). This provided a "broad coverage" of the available literature (Arksey & O'Malley, 2005). Common phrases that corresponded to FC (e.g., inverted learning, flipped classroom, inverting a class, and flipping a lesson), science-related subjects (e.g., science and biology), and K-12 education (e.g., primary school and secondary education) could thus be identified.

(3) Selecting studies, data extraction and synthesis

Inclusion and exclusion criteria were developed to select the studies, as shown in Table 1. To ensure studies with vigorous methodologies and reliable findings, the articles had to have been published in peer-reviewed journals. The time period of the search was also restricted from January 2012 to February 2020 (the time of writing) because few papers about FC were published before 2012 (Giannakos, et al., 2014). There was no restriction on the use of language in the research location, but the report of the studies was limited to English. The studies also had to be empirical research that reported the implementation of FC with learning outcomes in K-12 science education; and so numerous studies on the use of FCs in science disciplines in the higher education sector were excluded. The FC also had to satisfy Bishop and Verleger's (2013) definition of an FC, as the use of instructional videos to teach content knowledge in out-of-class time and face-to-face interactive learning activities in the classroom.

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Table 1

Inclusion and exclusion criteria for selection.

Criteria	Inclusion	Exclusion
Definition of FC	FC must make use of instructional videos to teach content knowledge in out-of-class time and face-to-face learning activities in the classroom.	FC did not include instructional videos to teach knowledge content in out-of-class time or did not have face-to-face learning activities.
Context	Studies must involve FC in the science subject in K-12 education (primary and secondary school).	Studies were outside K-12 science education, such as science in higher education, mathematics in primary school, etc.
Study focus	Studies must report empirical findings including impacts on student learning.	Studies did not investigate any aspects of learning outcomes.
Time period of search	January 2012 to February 2020.	Studies were outside these dates.
Type of articles	Studies published in peer-reviewed journals.	Studies were not peer-reviewed.
Language	English.	Non-English.

Using the search terms suggested, 358 peer-reviewed articles were identified as of February 14, 2020. Reviewing the titles and abstracts showed that many articles were irrelevant. These articles were primarily associated with the research of FC in higher education, studies on another meaning of “flip” in science (e.g., the inquiry-based activity of bottle flipping in science classrooms), and the literature on FCs without empirical findings. Numerous articles were also excluded as they were duplicated across different databases. Another five records were identified by searching reference lists from other identified articles, and two records traced from other reviews of FC that were not limited in their studies to the context of higher education (i.e., Lo & Hew, 2017; Zainuddin & Halili, 2016; Zainuddin et al., 2019). Finally, 25 full-text articles were assessed for eligibility, ten of which were excluded due to inappropriate context and study focus. Eventually, 15 articles were selected for the scoping review. Figure 1 illustrates the selection process of articles based on the Preferred-Reporting of Items for Systematic Reviews and Meta-Analyses statement (PRISMA;

Moher, Liberati, Tetzlaff, Altman, & The PRISMA Group, 2009).

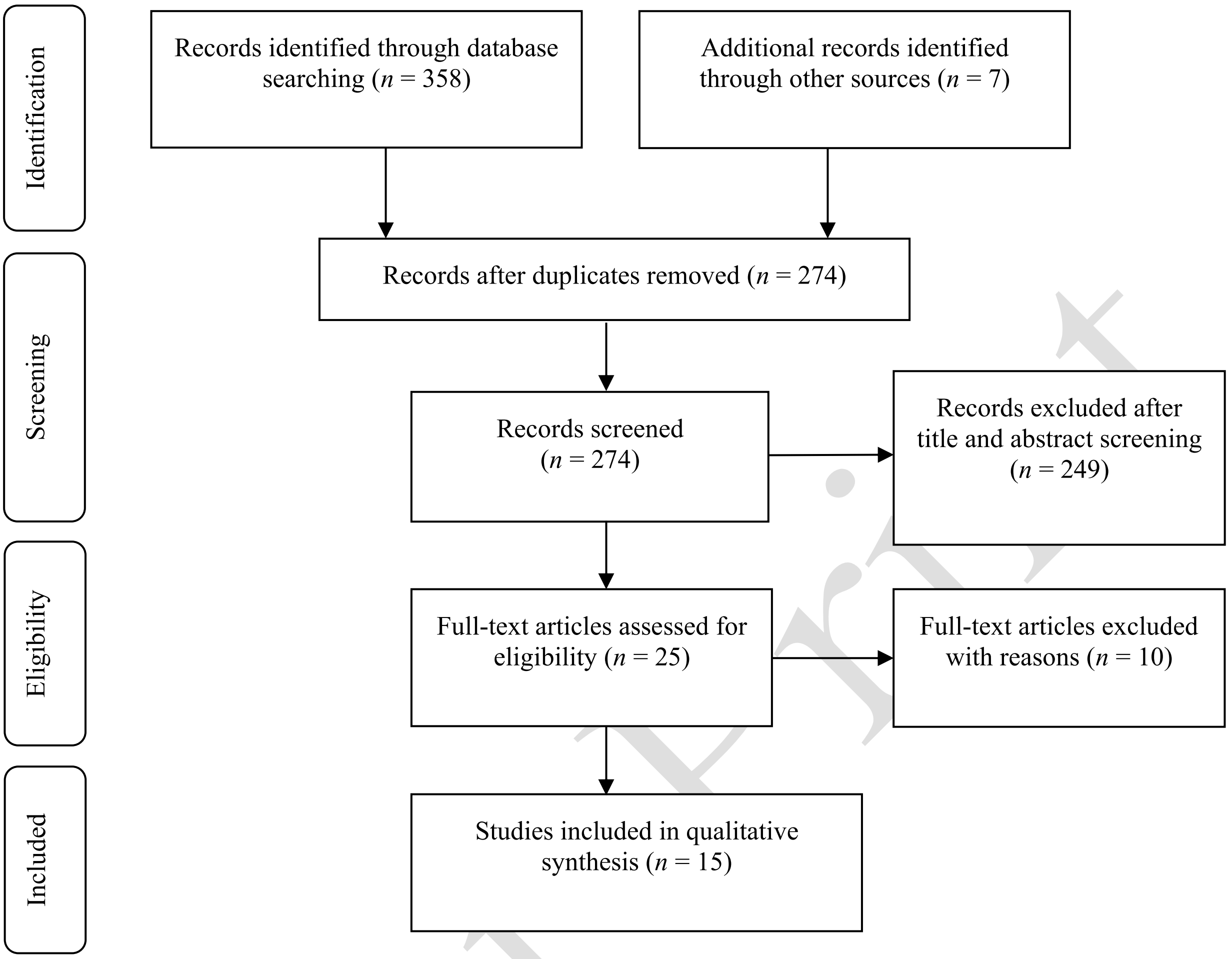

Figure 1. The selection process of articles based on PRISMA.

After the identification of the target studies, data extraction and analysis were conducted by the authors. To ensure the validity of the data extracted, in-depth and lengthy content analysis (Creswell, 2012) was performed in a step-by-step manner by the first author in order to extract and categorise the data of the scoped articles. As in other scoping reviews (e.g., Lo & Hew, 2017; O'Flaherty & Phillips, 2015), the data firstly comprised generic information about the studies, including the name of the author(s), location of the research, year of publication, research context (level and subject), sample size and research design (methodology) with the duration of intervention. Secondly, data was also categorised in terms of the flipped classroom design, which includes the theoretical or pedagogical framework grounded, pre-class, in-class, and after-class

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activities, and the learning management system (LMS) deployed. Thirdly, data involving the impact of FC was also categorised into different aspects (i.e., academic performance, skills, motivation, attitudes/satisfaction and engagement/participation) in accordance with other recently published systematic reviews of FC (Lo & Hew, 2017; Zainuddin & Halili, 2016; Zainuddin et al., 2019). Finally, data showing challenges, problems and disengagement was also coded and divided into three categories defined by Betihavas et al. (2016): student-related, faculty challenges, and operational challenges. Afterwards, all categorised data was summarised and synthesised narratively by tabulation for the mapping of evidence (Rodgers, 2009). The extracted data was checked and the grouping and clustering involved in the tables was also validated by the second author to improve the validity of the extracted and synthesised data. Compromise on disagreements concerning the above process was also followed by further data re-assessment from the two authors.

(4) Charting the data

As noted above, an overview of the generic information of the scoped studies is provided, for which the author, year, location of the study, context, sample size, and research design were noted, as shown in Table 2. The design of the FCs, theirs impacts and challenges are also summarised in Table 3 for the ease of evidence mapping (Munn et al., 2018).

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(5) Collating, summarising, and reporting the results

Table 2
An overview of the included studies of FC in K-12 science education.

Study (author and year)	Location of study	Context (level and subject)	Sample size	Research design (duration)
Atwa et al. (2016)	Palestine	Grade 11 Physics	FC (57)/TC (56)	[P-P]QE (1 topic)
Camiling (2017)	Philippines	Grade 2 STEM	FC (12)/TC (12)	[P-P]QE (2 weeks)
Çetinkaya (2017)	Turkey	Grade 7 Science	WBAFC (37)/TFC (37)	[P-P]QE (3 weeks)
Gariou-Papalexiou et al. (2017)	Greece	Grade 10 Biology	FC (17)	[P-P]NE, AR (1 topic)
Kettle (2013)	UK	Aged 16–18 Physics	FC (12)	NE (appeared to be 1 semester)
Leo and Puzio (2016)	USA	Grade 9 Biology	FC (42)/TC (29)	[P-P]QE (appeared to be 2 topics)
Lo et al. (2018) [#]	Hong Kong	Grade 9 Physics	FC (119)/TC (125)	[P]QE (10 weeks)
Olakanmi (2017)	Nigeria	Aged 13–14 Chemistry	FC (33)/TC (33)	[P-P]QE (3 weeks)
Schultz et al. (2014)	USA	Grade 10–12 Chemistry	FC (29)/TC (32)	[P]QE (4 months)
Sezer (2017)	Turkey	Grade 6 Science	FC (35)/TC (33)	[P-P]QE (2 weeks)
Slemmons et al. (2018)	USA	Grades 7–9 Chemistry	FC-S (77.84)/FC-L (76.07)	[P]QE (2 topics)
Sookoo-Singh and Boisselle (2018)	Trinidad and Tobago	Aged 14–15 Chemistry	FC (27)	[P-P]NE, AR (6 weeks)
Stratton et al. (2019)	USA	Grade 7 Science	FC (73)/TC (81)	[P-P]QE (3 weeks)
Yousefzadeh and Salimi (2015) [#]	Iran	Grade 7 Science	FC (25)/TC (25)	[P]QE (8 weeks)
Zainuddin (2018)	Indonesia	Aged 15–16 Science	GFC (27)/TFC (29)	[P]QE (12 weeks)

= multi-disciplinary study with other subjects, FC = flipped classroom, TFC = traditional flipped classroom, GFC = gamified flipped classroom, WBAFC = web-based assist flipped classroom, TC = traditional classroom, NE = non-experiment, QE = quasi-experiment, AR = action research, P-P = pre-test and post-test, P = post-test

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Table 3
Summary of the designs, impacts and challenges of FCs in K-12 science education extracted from scoped studies.

Study (author, year, location)	Grounded framework	Pre-class learning activities	In-class learning activities	Post-class learning	LMS	Category of impacts concerned	Impacts of FC on student science learning	Category of challenges addressed	Extracted data (textual quotes) about the challenges of FC in practice
Atwa et al. (2016) Palestine		Watch videos, answer short quizzes in Blendspace, discuss on Facebook.	Q&A, clicker poll on videos, active learning strategies, e.g., research projects.		Blend Space	Academic performance	Student achievement (post) scores in physics in FC were significantly better than those in TC [AP].	Student-related	"It may take more than one semester for the students to get accustomed to the FLM and value it."
Camiling (2017) Philippines	5E instruction model, FILP pillar	Watch (online/CD) videos, take notes and propose questions in notebooks.	Prepare questions for group discussions on videos, perform application activities, answer formative assessment.			Skills	Students in FC had significantly higher basic process skills according to mean test scores than those in TC [S].		
Çetinkaya (2017) Turkey	Assure Instructional Design model	Watch videos and view web-assisted materials.	Perform cooperative learning, complete web-assisted measurement and evaluation activities and quizzes.		Web-based platform	Academic performance	Post-test results analysis showed a positive significant difference in achievement in favour of the students in WBAFC compared to those in TFC [AP].		
Gariou-Papalexiou et al. (2017) Greece	Bloom's taxonomy, FILP pillar	Watch videos on content and experiment via LAMS.	Peer-discuss, clarify student misconceptions.	Student self-evaluation.	Web-based Learning Activity Manageme nt System (LAMS)	Academic performance and engagement	No significant difference between pre- and post-tests on "photosynthesis" was reported [AP]. Observation indicated student involvement and active participation in the educational process [E].	Student-related and operation-related	"Some others [students] did not even get into the platform."
								Operation-related	"It was found that they had no access to a computer or the Internet at home."
								Faculty-related	The implementation of the FC "demands more time and effort in order for the teacher to prepare the lesson."
Kettle (2013) UK		Watch videos via Moodle, take notes.	Taking notes, problem-solving.		Moodle	Academic performance and attitude	Mixed findings on student achievement [AP]. FC students considered in-class note-taking and problem-solving to be effective and enjoyable but watching videos to be ineffective and unenjoyable [A].	Faculty-related	"The searching for every video on every topic was a time-consuming process."
								Student-related and operation-related	"[Students] did not recall the key ideas, were not equipped for the problem-solving lesson and did not realise they were underprepared."
								Operation-related	"The school's 'net nanny' blocked all access to YouTube for students and some videos could only be accessed from home."
Leo and Puzio (2016) USA		Watch videos and complete quizzes via Moodle.	Active learning, such as projects, laboratories, and interactive forms of learning.		Moodle	Academic performance and attitude	Two quizzes and one post-test demonstrated statistically significant gains in FC learning [AP]. The qualitative results suggested that students may have benefited from the active learning strategies and enjoyed learning through FC [A].	Operation-related	"The school web interface, which promised to track student video usage, was not working properly."

Lo et al. (2018) Hong Kong[#]	Merrill's First Instruction	Watch videos, complete online follow-up exercises.	Brief review of out-of-class learning, mini-lecture, problem-solving.	Online platform (name not mentioned)	Academic performance, engagement, and social interaction	The levels of student achievement in physics were significantly higher in FC than in TC [AP]. Teachers' comments recognised the benefits of student participation in out-of-class learning [E] and more interaction with students [I].	Operation-related and faculty-related	"Two major challenges in using the flipped classroom approach were identified, namely the considerable start-up efforts required of the teachers and the students' lack of pre-class motivation"
Olakanmi (2017) Nigeria		Watch (DVD/online) videos, take notes.	Collaborative inquiry-based learning.		Academic performance, engagement and social interaction	Student mean scores of conceptual understanding of the rate of chemical reactions in FC were significantly higher than those in TC [AP]. Qualitative findings suggested FC benefits students to encourage in active learning through interactions with peers and teachers [E, I].	Student-related	"Most of them [students] felt that the new approach was a bit challenging for them initially as it took them some time to find their ways around the material."
Schultz et al. (2014) USA		Watch screencast videos (10–15 mins), complete reflection in Google Forms.	Five-minute review of video content, discussion, problem-solving.		Academic performance and attitude	Students in grade 11 in FC had significantly higher mean scores than those in TC for all eight assessments, gender difference was also significant (male > female) [AP]. Most students perceived FC positively [A].	Student-related and operation-related	"Negative features included the teacher being unavailable during video lectures, the videos were too long, missing a video and would get behind, missed classroom interaction, and technology issues. A unique negative issue reported was having two flipped classes created more homework."
Sezer (2017) Turkey	SCLT	Watch (CD / online) videos (simple videos / PowerPoint presentations with voice over), e-book and complete online quizzes.	Brainstorming, group discussion, and collaborative problem-solving.		Academic performance, motivation, and attitudes.	The FC generated a larger increase in student academic achievement scores and motivation scores in post-test than TC from two-way repeated-measures ANOVA [AP, M]. The result was supported by interviews with students. Interview finding revealed FC had a positive effect on student perceptions of the science course [A].	Faculty-related	"The preparation of the various electronic resources required for the application of the flipped classroom environment and the motivation of students is a very difficult job in the already busy professional life of teachers."
							Operation-related	"It is hoped that the flipped classroom environment supported by this technology will contribute positively to the outcome of this project and will improve student learning. These studies on classroom environment are limited in number, and it is an issue not much explored in the literature on Turkey."
Slemmons et al. (2018) USA	CLT, CTML	Watch videos, complete quizzes.	Interactive group learning (without detail).	Moodle	Engagement	ANOVA from tests and self-reported survey suggested that students had higher rates of retention of content and higher degrees of engagement and focus when learning from short videos [E].	Operation-related	"Determining whether students actually watched videos was limited."
Sookoo-Singh and Boisselle (2018) Trinidad and Tobago	SCLT	Watch videos, study lecture notes, animations, picture, PowerPoint presentations, stimulated lab.	Conduct hands-on activities (without detail).		Academic performance, motivation, and attitude	Academic achievement was not significantly affected by FC [AP]. Motivation was positively and significantly affected by FC [M]. Most students perceived the positive effects of the FC intervention [A].	Operation-related	"Students faced problems accessing the materials."
							Student-related and operation-related	"Some students, even though they had access to the materials, did not complete the lectures at home."

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Stratton et al. (2019) USA		Watch screencast videos, take notes, summarise the content, and propose questions.	Group discussion, practice tasks, and hands-on activities.		Academic performance, engagement, motivation, and attitude	ANOVA results showed no differences in performance between students with different learning abilities in FC and TC [AP]. Student survey data indicated that most students enjoyed learning about the FC and experienced increased engagement and motivation [A, E, M].	Student-related	"Students reported disliking having to wait for a response to questions [in out-of-class learning]."
Yousefzadeh and Salimi (2015) Iran		Watch videos.	Group discussions, collaborative problem-solving.		Academic performance	Student average scores of achievements in FC were significantly higher than those in TC [AP].	Student-related and operation-related	"If the students don't want to watch the videos or complete the activities before the class, they will be unprepared to use their new knowledge during the class time."
							Faculty-related	"Teachers involved with flipped classes must be prepared for time-consuming and demanding work." "[FC] requires the teachers to guide students as they apply their new knowledge in the classroom."
Zainuddin (2018) Indonesia	SDT	Watch videos, complete gamified quizzes online LMS	Group discussions and student presentations.	iSpring Learn	Academic performance, motivation, engagement, and social interaction	Two post-test scores in GFC were significantly higher than those in TFC [AP]. Most items in student perceived competence (4 out of 5) and autonomy (5 out of 5) were significantly higher in GFC than those in TFC. Only one item of perceived relatedness was significantly different between GFC and TFC [M]. The GFC setting fostered better engagement and social interaction [E, I].		

# = multi-disciplinary study with other subjects,
LAMS = learning activity management system, LMS = learning management system, SCLT = student-centred learning theory, CLT = cognitive load theory, CTML = cognitive theory of multimedia learning, SDT = self-determination theory
FC = flipped classroom, TFC = traditional flipped classroom, GFC = gamified flipped classroom, WBAFC = web-based assist flipped classroom, TC = traditional classroom, FLM = flipped learning model
Impacts studied: AP = academic performance, **A** = attitude, **M** = motivation, **E** = engagement/participation, **S** = skills, **I** = social interaction

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Findings and discussions

A. Overview of the scoped studies

This review scoped 15 studies from 11 countries, including four from the United States, two from Turkey, and one from each of the following regions: Greece, Hong Kong, Indonesia, Iran, Palestine, Philippines, Nigeria, Trinidad and Tobago, and the United Kingdom. As with the findings from other FC reviews (e.g., Lo & Hew, 2017; van Alten et al., 2019), the majority of the studies were undertaken within the United States, followed by Asian regions. There is a lack of research into FC in K-12 science in Taiwan, where FC studies have been dominated in other contexts (Lo & Hew, 2017). Moreover, the scoped FC studies were widely integrated in the subjects of physics (n = 4), chemistry (n = 4), biology (n = 2), science (n = 4), and STEM (n = 1) (see Table 2).

In terms of the research methodology, most of the scoped studies employed a quasi-experimental design (n = 12), including (a) a post-score study between FC and TC (n = 3), (b) pre- and post-score quasi-experiments between FC and TC (n = 7), (c) a post-score study between FC and TC (n = 1), and (d) pre- and post-score quasi-experiments between modified FC and TFC (n = 1). Some of the studies only employed a single-group non-experimental design (n = 3) to investigate the FC efficacy. To a certain extent, this variation in research design limits us in comparing the effectiveness of FC on student achievements (Lo & Hew, 2017).

More in-depth analysis is needed when considering the two studies (i.e., Çetinkaya, 2017; Zainuddin, 2018) that only compared student achievements between a modified FC and a TFC without a non-flipped TC control. As suggested, the significant results obtained from such a design can only indicate that the efficacy of the FC is caused by other factors rather than the flipped pedagogy (Jensen et al., 2015).

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A number of the scoped studies implemented the FC over a short period of time, ranging from 1 to 3 weeks (*n* = 9), suggesting that the significant effect on the improvement of student achievements was possibly due to the novelty effect, as suggested by other K-12 FC reviews (Lo & Hew, 2017). This improvement in student performance in these FCs was only caused by the introduction of technology in a short-term manner (Clark, 1983).

Lastly, there is a shortage of qualitative evidence of lesson observations for the in-class learning activities used to examine the improvement of student learning (*n* = 2, Gariou-Papalexiou et al., 2017; Olakanmi, 2017), reflecting the deficiency suggested by other FC researchers (e.g., Abeysekera & Dawson, 2015) and the need for more evidence from the triangulation of data in future K-12 science FC research.

B. The design of FCs in K-12 science education

Several researchers (e.g., Bishop & Verleger, 2013; Abeysekera & Dawson, 2015) have noted that it is vital to ground theoretical and pedagogical frameworks in an FC's design and implementation, however, less than half of the scoped studies (*n* = 7) employed a solid framework in the design and implementation of their FCs in K-12 science education (see Table 3). In particular, either an established theoretical (cognitive load theory, cognitive theory of multimedia learning, self-determination theory, student-centred learning theory) or pedagogical framework (Assure Instructional Design model, Bloom's taxonomy, 5E instructional model, Merrill's First Instruction) was grounded in the design and implementation of the FCs. A few (*n* = 2, Camiling, 2017; Gariou-Papalexiou et al., 2017) simply included the framework (e.g., the FLIP pillar of FC, Flipped learning Network, 2014) without an in-depth illustration of how that framework could be integrated into the FC theoretically and pedagogically. The FILP pillars framework can also only be regarded as a framework in defining the characteristics of FC instead of being a well-recognised and robust

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framework under research by scholars. Unlike other prominent FC studies in other disciplines (e.g., mathematics in elementary school, Lai & Hwang, 2016; undergraduate biology, Sletten, 2017; information communication technology in higher education, Çakıroğlu & Öztürk, 2017), self-regulated learning (SRL) theory is absent among the scoped studies. In particular, five of the studies grounded with framework reported significant and positive impacts of FC on student achievements. A framework grounded FC intervention would probably have a higher chance of yielding an effective influence on student achievements. However, it should be noted that only three out of the five framework-grounded FC studies had an impact on student academic performance. Due to the limited number of homogeneous studies scoped, there can be no definitive conclusion about which framework for the FC is the most effective in K-12 science education.

All scoped studies included a pre-class video-watching activity (*n* = 15), meeting the inclusion criteria of FC according to Bishop and Verleger's (2013) definition. Other than watching instructional videos before lessons, several pre-class learning activities were also identified in the K-12 flipped science classroom. They were quizzes (*n* = 5), note-taking (*n* = 4), online follow-up exercises (*n* = 1), studying from text-based (*n* = 2) and web-based materials (*n* = 1), online discussion (*n* =1), and reflection (*n* =1). In terms of the in-class learning, group discussions (*n* = 6), brief reviews of online content, including brainstorming and question and answer (Q&A) sessions on videos (*n* = 4), and problem-solving activities (*n* = 5) were the main learning activities found in the studies. Unfortunately, only a few of the studies (*n* = 3, e.g., Lo et al., 2018) described and discussed their in-class learning activities in a detail manner. Instead, only a small number mentioned hands-on activities (*n* = 2, Sookoo-Singh & Boisselle, 2018, Stratton et al., 2019) and inquiry-based learning (*n* = 1, Olakanmi, 2017) in the in-class learning of their FCs, however, their descriptions were also very sketchy.

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Nearly half the scoped studies (*n* = 7) deployed LMS to afford students pre-class activities. They include Moodle (*n* = 3, Kettle, 2013; Leo & Puzio, 2016; Slemmons et al., 2018), Blend Space (*n* = 1, Atwa et al., 2016), iSpring Learn (*n* = 1, Zainuddin, 2018), and a self-developed web-based learning activity management system (*n* = 2, Çetinkaya, 2017; Gariou-Papalexiou et al., 2017). One scoped research (Lo, et al., 2018) only mentioned the affordance of online platform for implementing students' pre-class video-watching and quizzes without stating the name of the LMS. Actually, a few studies suggested some advantages of incorporating their FCs with a LMS in their FCs. For example, the LMS acted as an affordance for providing videos and quizzes (Leo & Puzio, 2016) for ease of access (Kettle, 2013). The automatic scoring function and online gradebook function of LMS, such as Moodle and Blend Space was also applauded (e.g., Leo & Puzio, 2016; Zainuddin, 2018). The pedagogical support and the ability of authorship and supervision to follow the progress of the students' studies were also suggested (Gariou-Papalexiou et al., 2017).

Generally speaking, all scoped studies were comprised of pre-class video-watching and diversified in-class learning activities, and only one (i.e., Gariou-Papalexiou et al. 2017) organised after-class activities for students to conduct self-evaluation. No significant impact on student achievement was found to have incorporated after-class evaluation, however, suggesting future investigation of the exploitation of post-class follow-ups is required. Meanwhile, several scoped studies employed the LMS to supporting the out-of-class learning of students in terms of the affordance, management and analytical assessment of student learning in FC (Algayres & Triantafyllou, 2019).

C. The impact of FC on student science learning in K-12 education

Most of the scoped studies evaluated student academic performance (*n* = 13), and several assessed student motivation (*n* = 4), engagement or participation in flipped learning (*n* = 6), attitudes toward their learning (*n* = 6), and social interaction (*n* = 3) in the flipped classrooms. A very few studies investigated the efficacy of FC on the development of scientific learning skills, such as science process skills (*n* = 1). The impacts of FC identified from the scoped studies are categorised in Table 4.

Among the 13 studies evaluating student academic performance, only over half of the studies revealed a positive effect on the efficacy of FC on student academic achievement (*n* = 9), while numerous studies reported a non-significant result or mixed findings in their quantitative research between the flipped learning treatment group and the traditional learning counterparts (*n* = 4). The findings actually echoed 'the positive and at least neutral' results obtained in the recent review of FC in K-12 education in various subjects other than science (Lo & Hew, 2017).

Table 4
Summary of the effects on student achievements identified from the scoped studies.

Category of impacts on student achievements		**Scoped studies (name and year)**
Academic performance (*n* = 13)	positively significant (*n* = 9)	Atwa et al. (2016), Çetinkaya (2017), Leo and Puzio (2016), Lo et al. (2018), Olakanmi (2017), Schultz et al. (2014), Sezer (2017), Yousefzadeh and Salimi (2015), Zainuddin (2018)
	non-significant (*n* = 4)	Gariou-Papalexiou et al. (2017), Kettle (2013), Sookoo-Singh and Boisselle (2018), Stratton et al. (2019)
Engagement (*n* = 6)		Gariou-Papalexiou et al. (2017), Lo et al. (2018), Olakanmi (2017), Slemmons et al. (2018), Stratton et al. (2019), Zainuddin (2018)
Attitudes (*n* = 6)	towards flipped approach (*n* = 5)	Kettle (2013), Leo and Puzio (2016), Schultz et al. (2014), Sookoo-Singh and Boisselle (2018), Stratton et al. (2019
	towards subject (*n* = 1)	Sezer (2017)
Motivation (*n* = 4)		Sezer (2017), Sookoo-Singh and Boisselle (2018), Stratton et al. (2019), Zainuddin (2018)
Social interaction (*n* = 3)	during pre-class learning (*n* = 1)	Zainuddin (2018)
	during in-class learning (*n* = 3)	Lo et al. (2018), Olakanmi (2017), Zainuddin (2018)
Skills (*n* = 1)	science process skills (*n* = 1)	Camiling (2017)

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Specifically, several scoped studies suggested that the FC is beneficial for students in terms of their self-paced and autonomous learning (Giannakos et al., 2014; Lo & Hew, 2017). For example, Schultz (2017) revealed that their students in the FC were able to pause, rewind, and review video lectures at their own pace, and catch up when absent. On the other hand, few scoped studies attributed the significant improvement of student performance to their flipped classroom design. For instance, Zainuddin (2018) indicated that students in his gamified FC felt more competent in the inside-class and out-of-class learning activities, especially during the competition to earn points and badges in the gamified quiz section. However, only few scoped studies discussed the ineffectiveness of their FCs. Several of the scoped studies attributed the insignificant results to the limitations of the research design as well as the challenges of the study.

Achievements other than academic performance (i.e., student motivation, engagement, attitudes, and social interaction), were all found to be improved in the scoped studies (*n* = 12). Moreover, all the scoped (quasi) experimental studies revealed a significantly better improvement in these achievements in the FC when compared with traditional learning counterparts in a K-12 science context (*n* = 5). This corresponds to the findings in Lo and Hew's (2017) review of FC studies among various subjects in K-12 education, as well as those of other reviews of FC in higher education (e.g., Betihavas et al. 2016; O'Flaherty & Phillips, 2015; Giannakos et al., 2014; Seery 2015). Despite the positive findings regarding affective achievements, there was a very differentiated depth of evidence supporting the results. For instance, Slemmons et al. (2018) systematically compared student engagement with different length of videos (short/long) through quantitative statistical analysis on the tests and survey. Similarly, Zainuddin (2018) statistically compared the perceived motivation of students in the gamified FC in terms of perceived competence, autonomy, and relatedness with the TFC counterparts. On the other hand, Stratton et al. (2019) drew conclusions about the impact of FC on student motivation and engagement through

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simple descriptive statistics from student surveys, and Gariou-Papalexiou et al. (2017) drew conclusions about student active involvement and engagement in the in-class activities of the FC through class observation.

As with the findings of other FC studies outside the K-12 science context, the scoped K-12 science FC (e.g., Gariou-Papalexiou et al., 2017; Lo et al., 2018) was able to motivate and engage students to learn actively because of the benefits of FC in terms of the value of self-paced learning during the pre-class video-watching and follow-up quizzes, as well as the interactive learning in the in-class learning environment (Bishop & Verleger, 2013; Chen et al., 2014). These benefits were also attributed to the improvement in student attitudes towards the FC approach (Kettle, 2013, Leo & Puzio, 2016; Schultz et al., 2014) and the science subject itself (Sezer, 2017).

Many scoped studies reported the benefits of FC in creating more interactions among students, and between the teacher and students. For example, Lo et al. (2018) suggested that the flipped approach encouraged students to ask more questions and teachers to provide more assistance during the in-class learning. Olakanmi (2017) also mentioned that students in the FC benefited from adequate preparation for the lesson before the classes and had the chance to interact with peers and the teacher in the -in-class learning. Zainuddin (2018) reported that the gamified FC enabled his students to interact with peers not only during the in-class face-to-face learning, but also in the online gamification platform, as students might track the progress of other students on the leaderboard during the competition. Such social interaction also attributed to social engagement in the gamified FC (Zainuddin, 2018).

Unlike other educational contexts reviewed (e.g., mathematics in elementary school, Lai & Hwang, 2016; undergraduate math, Sun et al., 2018; information communication technology in higher education, Çakıroğlu & Öztürk, 2017), research into FC in K-12 science education on the improvement of student metacognitive skills, such as self-regulated learning (SRL), was absent in this scoping review. The evaluation of subject-specific achievements, such as scientific literacy and science process skills, were also limited in the FC studies at K-12 science education. There is also a limited investigation (*n* = 1; Stratton et al. 2019) of the effect of FC on students with different learning abilities, suggesting more future studies are required.

D. The challenges of flipped learning among the scoped studies in K-12 science education

Several challenges, including student-related, faculty-related, and operation-related challenges, as categorised by Betihavas et al. (2016), were addressed among the scoped studies. The challenges identified from the scoped studies are categorised in Table 5.

Table 5

Summary of the challenges of FC identified from the scoped studies.

Category of challenges		**Scoped studies (name and year)**
Operation-related (*n* = 10)	Difficulty of ensuring students watch the instructional videos before the lesson (*n* = 6)	Gariou-Papalexiou et al. (2017), Kettle (2013), Lo et al. (2018), Slemmons et al. (2018), Sookoo-Singh and Boisselle (2018), Yousefzadeh and Salimi (2015)
	Problems with accessing the online videos (*n* = 4)	Gariou-Papalexiou et al. (2017), Kettle (2013), Schultz et al. (2014), Sookoo-Singh & Boisselle (2018)
	Limited infrastructure in students pre-class learning (*n* = 1)	Sezer (2017)
	Accidental malfunctioning of online platforms (*n* = 1)	Leo and Puzio (2016)
Student-related (*n* = 8)	Student reluctance and lack of motivation for pre-class learning (*n* = 4)	Gariou-Papalexiou et al. (2017), Lo et al. (2018), Sookoo-Singh and Boisselle (2018), Yousefzadeh and Salimi (2015)
	Initial struggles on familiarising with the FC (*n* = 3)	Atwa et al. (2016), Olakanmi (2017), Schultz et al. (2014)
	The long duration of videos, heavy workload, and lack of rapid out-of-class support from teachers (n = 2)	Schultz et al. (2014), Stratton et al. (2019)
Faculty related	Difficulty of finding suitable instructional videos (*n* = 3)	Lo et al (2018), Olakanmi (2017), Zainuddin (2018)

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(*n* = 5)	Demand of time and effort for the preparation and implementation of in-class learning activities (*n* = 2)	Gariou-Papalexiou et al. (2017), Yousefzadeh and Salimi (2015)

More than half the 15 studies reported different aspects of operation-related challenges in their FC interventions (*n* = 10). One of the most common operation-related challenges was the difficulty of ensuring students watch the instructional videos before the lesson (*n* = 6). Limited infrastructure (*n* = 1), the accidental malfunctioning of online platforms (*n* = 1), and problems accessing the online videos (*n* = 4) were also identified, regardless of the information technology infrastructure and accessibility to the internet in the countries.

Student reluctance and lack of enthusiasm to participate in out-of-class learning (*n* = 4), initial struggles familiarising students with the FC (*n* =3), the long duration of videos, heavy workload, and a lack of rapid out-of-class support from teachers (*n* = 2) were identified as student-related challenges (*n* = 8).

Regarding the faculty-related challenges identified in the scoped studies (*n* = 5), some of the scoped studies suggested that more time and effort was needed for the teachers to implement the FC in practice, such as preparing in-class student-centred activities (*n* = 2). Difficulty finding suitable instructional videos for the FC (*n* =3) was also a common faculty-related challenge in K-12 science education.

As with other subjects, such as mathematics, the operation-related challenge of difficulty in ensuring students watch the instructional videos before their lessons was found to be the most common obstacle in K-12 science classes (Lo & Hew, 2017). The causes of this challenge might be also student-related, due to student demotivation to participate in out-of-class activities caused by the unchallenging video-watching task (Lo & Hew, 2017).

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To address this challenge, interesting and innovative strategies for pre-class learning, such as gamification competitions (Zainuddin, 2018) and mobile lab investigations (Yeung et al., 2019), are recommended. Another way to motivate students to participate in the pre-class learning is to incorporate a self-regulated monitoring system into FC, in where students are guided to set learning goals and perform self-evaluation in accordance with flipped learning (Lai & Hwang, 2016).

The identified faculty-related challenges also resonate with the first-order barrier that K-12 teachers may encounter in FC in Hong Kong (Wang, 2017). This includes barriers to the accessibility of technology for students, and the preparation time, training, and support required from teachers to initiate the FC integration (Wang, 2017). A successful experience of the integration of FC in K-12 science education should thus be demonstrated for teachers in order to eliminate their concerns.

Further analysis and implications for the design of FC in K-12 science education

In this review, the designs, impacts, and challenges of the FC in K-12 science education were examined, summarised, and discussed. In this section, the scoped studies are further analysed using a refined Spector's six pillar for FC (Lo, 2018) to examine the limitations of the K-12 science FC in the current studies. This content analysis was based on Lo and Hew (2017)'s 10 guidelines for the design and implementation of FC, as well as Lo's (2018) refined 10 recommendations for flipping a classroom basing on Spector's (2016) six-pillar framework for educational technology. The results of the analysis are summarised in Table 6.

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Table 6

Analysis of the scoped studies based on the refined Spector's six pillars framework.

Study (author, year)	Spector's Six Pillars					
	Communication	Interaction	Environment	Culture	Instruction	Learning
Atwa et al. (2016)*	C1 C2	I3 I4		C7		L9 L10
Camiling (2017)*			E5	C7	I8	L10
Çetinkaya (2017)*		I4	E5	C7	I8	L10
Gariou-Papalexiou et al. (2017)	C1		E5	C7	I8	L10
Kettle (2013)				C7		L9 L10
Leo and Puzio (2016)*		I4		C7		L10
Lo et al. (2018)#*	C2	I4	E6	C7	I8	L9 L10
Olakanmi (2017)*	C1	I4		C7		L10
Schultz et al. (2014)*	C1 C2		E6	C7		L10
Sezer (2017)*		I4	E5	C7		L10
Slemmons et al. (2018)*	C1 C2	I4			I8	L10
Sookoo-Singh and Boisselle (2018)	C1		E5	C7	I8	
Stratton et al. (2019)	C1		E5	C7		L10
Yousefzadeh and Salimi (2015)*#				C7		L10
Zainuddin (2018)*		I4		C7	I8	L10

= multi-disciplinary study with other subjects, * = positively significant results obtained

C1 = Introduce the flipped classroom approach to students and obtain parental consent, C2 = Use cognitive theory of multimedia learning to inform the production of instructional videos, I3 = Create a discussion forum for online interactions, I4 = Provide online quizzes on video lectures with computerised feedback, E5 = Provide human resources and technical resources to support flipped classroom practices, E6 = Adopt a school/faculty-wide approach to flipped classroom practices, C7 = Cultivate a classroom culture for learner-centred instruction, I8 = Utilise established models as the framework for flipped classroom design, L9 = Provide optimally challenging learning tasks with instructor's guidance, L10 = Use peer-assisted learning approaches during class meetings

The analysis suggested that most of the K-12 science FC studies emphasised two pillars: the "Culture" pillar (C7), which focuses on cultivating learner-centred instruction in the classroom culture (*n* = 14), and the "Learning" pillar (L10), which provides peer-assisted learning approaches during in-class meetings (*n* = 14). "Instruction" pillars (I8) that ground the FC in an established framework were also identified in some of the scoped studies (*n* = 7).

The "Interaction" pillar (I3) that provides a discussion forum for students to interact and ask questions (*n* = 1), however, as well as the "Learning" pillar (L9) that provides students with optimally challenging learning tasks inside the classroom (*n* = 3), were overlooked by most of the scoped studies. Although online or synchronised out-of-class communication is not essential in FCs in K-12 education, 'engaging students in seamless communication with their peers and teachers across various learning spaces, including at-home, in-class, and in-field learning' was suggested to positively affect student achievement and satisfaction (Hwang, Lai, & Wang, 2015). Other research also suggested that the creation of a discussion forum for online Q&A sessions is necessary to promote student engagement (Bhagat et al., 2016). Optimal challenges in in-class learning, together with the teacher's guidance, were also found to be effective in improving student achievement in the "Learning" pillar (L9) (Lo et al, 2018; Zainuddin, 2018), yet they are limited in the scoped studies specialising in K-12 science education.

More emphasis should have been placed in the analysis on developing K-12 science FC in a framework-grounded, science-specific, and challenging manner. A stimulating, effective, and established constructivist strategy, predict-observe-explain (POE; White & Gunstone, 1992), could be incorporated into FC to meet the needs of science subjects, as well as to overcome the challenges identified and discussed in the previous section.

In the traditional science classroom, POE has often been employed in the form of experiments in science laboratories to increase student motivation (Schraw, Crippen, & Hartley, 2006) and clarify scientific misconceptions (Bahar, 2003; Cinici & Demir, 2013), and a technology-enhanced environment with the use of mobile data loggers and a LMS to facilitate the POE activities outside of the classroom was proposed in FCs (Yeung et al., 2019). Figure 2 illustrates some features of this proposed FC.

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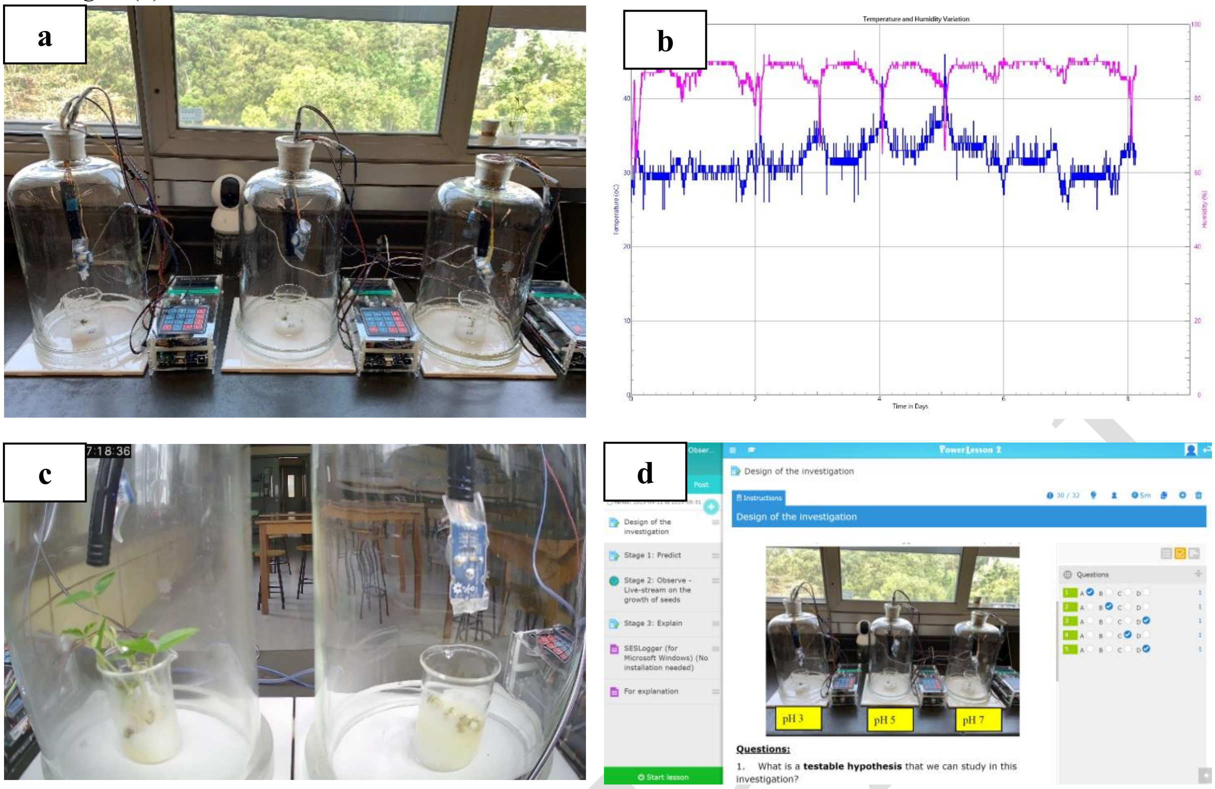

Figure 2. Technology-enhanced POE strategy with the use of mobile data loggers and a LMS in a flipped science classroom. **(a)** Setup of the mobile data loggers for the POE activity in a science laboratory. **(b)** Screenshot of the automatic graph-plotting function with the help of the logger application. **(c)** Camera image of the growth of seedlings during student observations. **(d)** Pre-class online POE activity afforded by a LMS.

In this modified FC, students should first set goals and make predictions about certain scientific investigations in the LMS. Then, students should self-monitor by making observations and measurements of their investigations with an IP camera alongside a mobile data logger. They should then self-evaluate by explaining and reconciling differences between their observations and previous predictions, as well as clarifying their externalised misconceptions. The LMS also facilitates online communication between the teacher and students, satisfying the recommendation for the "Interaction" pillar (I3) in this FC. The out-of-class POE activity will be grounded with SRL strategy as the theoretical framework, in which students can experience three phases of self-

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regulatory processes (Zimmerman, 2002), as illustrated in Figure 3.

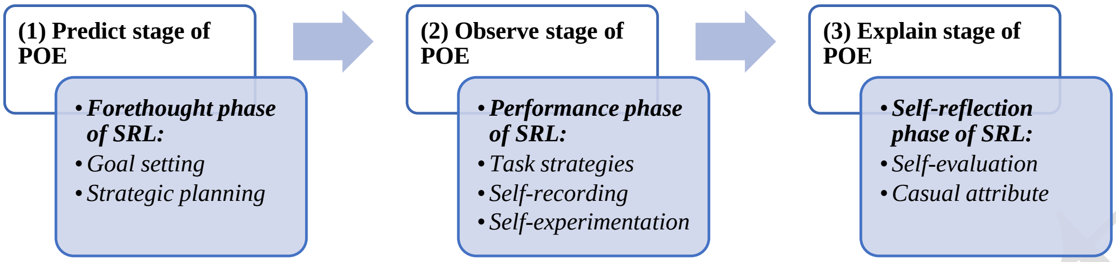

Figure 3. SRL theoretical framework for the out-of-class POE activities.

After finishing the technology-enhanced POE activities, students are expected to engage in face-to-face lessons involving a mini-lecture, a short briefing about the pre-class learning and subsequent inquiry-based learning activities.

In fact, this modified FC has begun to be implemented into the school curriculum during the period of class suspension due to the COVID-19 epidemic in Hong Kong (Fung, 2020). Although much positive feedback has been reported from the teachers and students, there is still a lack of empirical studies addressing the synergetic effect of the incorporation of the technology-enhanced POE and SRL strategy in a flipped learning environment. Further research to comprehensively integrate and investigate the efficacy of the modified FC in promoting student scientific literacy in K-12 science education is thus highly anticipated.

Limitations

This scoping review was limited by the insufficient number of studies (n = 15) that met the inclusion criteria. To ensure the quality of the available evidence, only the studies published in peer-reviewed journals were selected, however, not every scoped study (n = 2) was verified by well-recognised database indicators such as the Social Sciences Citation Index (SSCI), SCImago Journal Rank (SJR), and CiteScore. The exclusion of studies in conferences, unpublished doctor

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dissertations, master's thesis, and online articles might also hinder us from gathering more relevant evidence regarding FC research in K-12 science education. There was also a risk of missing some relevant studies that were written in non-English languages, as only English-written journal articles were included. Coverage of the evidence might also be restricted, as the search strategy was applied to only seven major relevant electronic databases.

Conclusions and Recommendations for Future Research

This scoping review of the 15 identified studies provides an up-to-date overview of the design and implementation of FC in K-12 science classes. Varied research designs and results regarding the efficacy of FC on student achievements, especially academic performance, have been found. In line with some of the recommendations suggested by the existing FC reviews in other contexts and the findings obtained from this scoping review, future research into FC in K-12 science education should take the following approaches so that the full potential of FC can be investigated in this area:

1. Ground the design of FC in an established framework that is pedagogically and theoretically suitable for K-12 science education, such as the modified FC integrated with technology-enhanced POE and self-regulated learning (SRL) strategies (Abeysekera & Dawson, 2015; Karabulut-Ilgu, Jaramillo Cherrez, & Jahren, 2018; Lo, 2018; O'Flaherty & Phillips, 2015).
2. Evaluate student learning outcomes that particularly improve student learning and development (Bernard, 2015; Karabulut-Ilgu et al., 2018; O'Flaherty & Phillips, 2015), specifying the objectives or needs of K-12 science education, such as scientific literacy, science process skills, as well as metacognitive skills like self-regulation in science.
3. Conduct a mixed-methods study that contains both quantitative and qualitative findings,

which includes interviews, lesson observations, and analyses of student work (Abeysekera & Dawson, 2015; Giannakos, et al., 2014; Karabulut-Ilgu, et al., 2018; Lo, 2017; Seery; 2015).

4. Employ a valid design that consists of a modified FC treatment group, a FC control group, and the additional control group of a non-flipped conventional classroom for meaningful comparison (Lo, 2017; Lo & Hew, 2017).
5. Implement the FC intervention for a longer period (e.g., one school year) to avoid any novelty effect (Karabulut-Ilgu, et al., 2018; Lo & Hew, 2017).

As FC studies in other contexts have suggested that there was a discrepancy in terms of the impacts of FC on students with different learning abilities (e.g., Jong, 2017; Nouri, 2016), the effect of FC among students with different learning abilities should also be further explored to address learning diversity in K-12 science classrooms (Yeung, Lee & Lam, 2012; Yeung, Lee, Wong, & Wong, 2013).

In conclusion, this rigorous and transparent scoping review helped to scope the literature and identify the gaps in research findings, specifically for K-12 science education, although the number of K-12 science FC studies was still in an embryonic and growing stage. This scoping review can definitely serve as a precursor to future systematic reviews and meta-analyses (Munn et al., 2018), in which the preliminary evidence obtained in this scoping stage of study can be further highlighted and analysed.

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References

References marked with an asterisk (*) indicate studies included in the scoping review

Abeysekera, L., & Dawson, P. (2015). Motivation and cognitive load in the flipped classroom: Definition, rationale and a call for research. *Higher Education Research and Development, 34*(1), 1-14.

Algayres, M. G., & Triantafyllou, E. (2019). Online environments for supporting learning analytics in the flipped classroom: A scoping review. In R. Ørngreen, M. Buhl, & B. Meyer (Eds.), *Proceedings of the 18th European Conference on e-Learning (ECEL 2019)* (pp. 16-23). Copenhagen, Denmark: Academic Conferences and Publishing International.

Arksey, H., & O'Malley, L. (2005). Scoping studies: Towards a methodological framework. *International Journal of Social Research Methodology, 8*(1), 19-32.

*Atwa, Z., Din, R., & Hussin, M. (2016). Effectiveness of flipped learning in physics education on Palestinian high school students' achievement. *Journal of Personalized Learning, 2*(1), 73-85.

Bahar, M. (2003). Misconceptions in biology education and conceptual change strategies. *Educational Sciences: Theory & Practice 3*(1): 55-64.

Bernard, J. S. (2015). The flipped classroom: Fertile ground for nursing education research. *International Journal of Nursing Education Scholarship, 12*(1), 99-109.

Bergmann, J., & Sams, A. (2012). *Flip your classroom: Reach every student in every class every day.* Eugene, OR: International Society for Technology in Education.

Betihavas, V., Bridgman, H., Kornhaber, R., & Cross, M. (2016). The evidence for 'flipping out': A systematic review of the flipped classroom in nursing education. *Nurse Education Today, 38*, 15-21.

Bhagat, K. K., Chang, C. N., & Chang, C. Y. (2016). The impact of the flipped classroom on mathematics concept learning in high school. *Educational Technology & Society, 19*(3), 134-142.

Bishop, J. L., & Verleger, M. A. (2013, June). The flipped classroom: A survey of the research. *In ASEE National Conference Proceedings, Atlanta, GA*.

*Camiling., M.K. (2017). The flipped classroom: Teaching the basic science process skills to high-performing 2nd grade students of Miriam College Lower School. *IAFOR Journal of Education, 5*(SI). 213-230.

Çakıroğlu, Ü., & Öztürk, M. (2017). Flipped classroom with problem based activities: Exploring self-regulated learning in a programming language course. *Educational Technology & Society*, *20*(1), 337-349.

*Çetinkaya, M. (2017). Designing and applying web assisted activities to be used in flipped classroom model. *International Journal of Evaluation and Research in Education, 6*(2), 128-137.

Chen, Y., Wang, Y., Kinshuk, & Chen, N. S. (2014). Is FLIP enough? Or should we use the FLIPPED model instead?. *Computers & Education*, 79, 16-27.

Cinici, A., & Demir, Y. (2013). Teaching through cooperative POE tasks: A path to conceptual Change. *The Clearing House: A Journal of Educational Strategies, Issues and Ideas, 86*(1), 1-10.

Clark, R. E. (1983). Reconsidering research on learning from media. *Review of Educational Research, 53*(4), 445–459.

Creswell, J. W. (2012). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research (4th ed.)*. Upper Saddle River, NJ: Pearson Education.

Curriculum Development Council. (2017). *Supplement to the science education key learning area curriculum guide (secondary 1-3).* Hong Kong: Curriculum Development Council.

Department for Education (2011). *Review of the National Curriculum in England. What can we learn from English, mathematics and science curricula of high-performing jurisdictions*. Retrieved June 26, 2020, from

Lee, L. H., & Yeung, Y. Y. (2021). A scoping review of flipped classrooms in K-12 science education: Implications and recommendations for future research and practice. *Journal of Computers in Mathematics and Science Teaching,40*(1), 65-97.

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/197636/DFE-RR178a.pdf

Enfield, J. (2013). Looking at the Impact of the flipped classroom model of instruction on undergraduate multimedia students at CSUN. *TechTrends, 57*(6), 14-27.

Faulkner, T., & Green, J. (2015). The peer instruction flipped learning model. In A. Scheg (ed.), *Implementation and critical assessment of the flipped classroom experience* (pp. 196-217). Hershey, PA: IGI Global.

Flipped Learning Network (FLN). (2014). *The four pillars of F-L-I-P*. Retrieved June 26, 2020, from https://flippedlearning.org/wp-content/uploads/2016/07/FLIP_handout_FNL_ Web.pdf

Fung, K. N. (2020 May 28). Secondary school students never cease learning by participating in EdUHK's 'mobile laboratory' (in Chinese). *Hong Kong Economic Times*. Retrieved June 26, 2020, from https://topick.hket.com/article/2655185?r=cpsdlc

*Gariou-Papalexiou, A., Papadakis, S., Manousou, E., & Georgiadu, I. (2017). Implementing a flipped classroom: A case study of biology teaching in a Greek high school. *Turkish Online Journal of Distance Education*, *18*(3), article 3.

Giannakos, M. N., Krogstie, J., & Chrisochoides, N. (2014, November). Reviewing the flipped classroom research: reflections for computer science education. In *Proceedings of the Computer Science Education Research Conference*, 23–29.

González-Gómez, D., Jeong, J., Rodríguez, D. A., & Cañada-Cañada, F. (2016). Performance and perception in the flipped learning model: an initial approach to evaluate the effectiveness of a new teaching methodology in a general science classroom. *Journal of Science Education and Technology, 25* (3), 450–459.

Hew, K., & Lo, C. K. (2018). Flipped classroom improves student learning in health professions education: A meta-analysis. *BMC Medical Education. 18,* article 38.

Hwang, G., Lai, C., & Wang, S. (2015). Seamless flipped learning: A mobile technology-enhanced flipped classroom with effective learning strategies. *Journal of Computers in Education. 2*(4), 449-473.

Jensen, J. L., Kummer, T. A., & Godoy, P. D. D. M. (2015). Improvements from a flipped classroom may simply be the fruits of active learning. *CBE-Life Sciences Education, 14*(1), article 5.

Jong, M. S. Y. (2017). Empowering students in the process of social inquiry learning through flipping the classroom. *Educational Technology & Society*. *20*(1), 306-322.

Karabulut-Ilgu, A., Jaramillo Cherrez, N. and Jahren, C.T. (2018), A systematic review of research on the flipped learning method in engineering education. *British Journal of Educational Technology, 49*, 398-411.

*Kettle, M. (2013). Flipped physics. *Physics Education, 48*(5), 593-596.

Lai, C. L., & Hwang, G. J. (2016). A self-regulated flipped classroom approach to improving students' learning performance in a mathematics course. *Computers & Education, 100*, 126-140.

Lee, M. (2018). Flipped classroom as an alternative future class model? implications of South Korea's social experiment. *Educational Technology Research and Development, 66*(3), 837-857.

*Leo, J., & Puzio, K. (2016). Flipped instruction in a high school science classroom. *Journal of Science Education and Technology*, *25*(5), 775-781.

Lin, H., & Hwang, G. (2019). Research trends of flipped classroom studies for medical courses: A review of journal publications from 2008 to 2017 based on the technology-enhanced learning model. *Interactive Learning Environments, 27*(8), 1011-1027.

Lo, C. K. (2017). Toward a flipped classroom instructional model for History education: A call for research. *International Journal of Culture and History*, *3*(1), 36-43.

Lo, C. K. (2018). Grounding the flipped classroom approach in the foundations of educational technology. *Educational Technology, Research and Development,* 1-19.

Lo, C. K., & Hew, K. F. (2017). A critical review of flipped classroom challenges in K-12 education: Possible solutions and recommendations for future research. *Research and Practice in Technology Enhanced Learning, 12*(1), 1-22.

*Lo, C. K., Lie, C. W., & Hew, K. F. (2018). Applying "First Principles of Instruction" as a design theory of the flipped classroom: Findings from a collective study of four secondary school subjects. *Computers & Education, 118*, 150-165.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D., & The PRISMA Group (2009). Preferred reporting items for Systematic Reviews and Meta-Analyses: The PRISMA statement. *Physical Therapy, 89*(9), 873-880.

Munn, Z., Peters, M.D.J., Stern, C., Tufanaru, C., Mcarthur, A., & Aromataris, E. (2018). Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. *BMC Medical Research Methodology, 18*(1),1-7.

National Research Council (1996). *National science education standards*. Washington, DC: National Academies Press.

Nouri, J. (2016). The flipped classroom: For active, effective and increased learning – especially for low achievers. *International Journal of Educational Technology in Higher Education, 13*(1), 1-10.

O'Flaherty, J., & Phillips, C. (2015). The use of flipped classrooms in higher education: A scoping review. *The Internet and Higher Education, 25*, 85-95.

OECD. (2019). *PISA 2018 Assessment and Analytical Framework.* PISA. Paris: OECD Publishing.

*Olakanmi, E. E. (2017). The effects of a flipped classroom model of instruction on students' performance and attitudes towards chemistry. *Journal of Science Education and Technology*, *26*(1), 127-137.

Rodgers, M., Sowden, A., Petticrew, M., Arai, L., Roberts, H., Britten, N., & Popay, J. (2009).

Testing methodological guidance on the conduct of narrative synthesis in systematic reviews: effectiveness of interventions to promote smoke alarm ownership and function. *Evaluation, 15*(1), 49-73.

Schraw, G., Crippen, K. J., & Hartley, K. (2006). Promoting self-regulation in science education: Metacognition as part of a broader perspective on learning. *Research in Science Education*, *36*, 111-139.

*Schultz, D., Duffield, S., Rasmussen, S.C., & Wageman, J. (2014). Effects of the flipped classroom model on student performance for advanced placement high school chemistry students. *Journal of Chemical Education*, *91*(9), 1334-1339.

Seery, M. (2015). Flipped learning in higher education chemistry: Emerging trends and potential directions. *Chemistry Education Research and Practice, 16*(4), 758-768.

Sergis, S., Sampson, D.G., & Pelliccione, L. (2018). Investigating the impact of flipped classroom on students learning experiences: A self-determination theory approach. *Computers in Human Behavior, 78*, 368-378.

*Sezer, B. (2017). The effectiveness of a technology-enhanced flipped science classroom. *Journal of Educational Computing Research, 55*(4), 471-494.

Sletten, S. (2017). Investigating flipped learning: Student self-regulated learning, perceptions, and achievement in an introductory biology course. *Journal of Science Education and Technology, 26*(3), 347-358.

*Slemmons, K., Anyanwu, K., Hames, J., Grabski, D., Mlsna, J., Simkins, E., & Cook, P. (2018). The impact of video length on learning in a middle-level flipped science setting: Implications for diversity Inclusion. *Journal of Science Education & Technology*, *27*(5), 469-479.

*Sookoo-Singh, N., & Boisselle, L. N. (2018). How does the "Flipped classroom model" impact on student motivation and academic achievement in a chemistry classroom? *Science Education International*, *29*(4), 201-212.

Spector, J. M. (2016). *Foundations of educational technology: Integrative approaches and interdisciplinary perspectives (2nd ed.)*. New York: Routledge.

*Stratton, E., Chitiyo, G., Mathende, A. M., & Davis, K. M. (2019). Evaluating flipped versus face-to-face classrooms in middle school on science achievement and student Perceptions. *Contemporary Educational Technology*, *11*(1), 131-142.

Sun, Z., Xie, K., & Anderman, L. (2018). The role of self-regulated learning in students' success in flipped undergraduate math courses. *Internet And Higher Education, 36*, 41-53.

van Alten, D. C. D., Phielix, C., Janssen, J., & Kester, L. (2019). Effects of flipping the classroom on learning outcomes and satisfaction: A meta-analysis. *Educational Research Review*, *28*, 100281.

Vieira, R., & Tenreiro-Vieira, M. (2016). Fostering scientific literacy and critical thinking in elementary science education. *International Journal of Science and Mathematics Education, 14*(4), 659-680.

Wang, T. (2017). Overcoming barriers to 'flip': Building teacher's capacity for the adoption of flipped classroom in Hong Kong secondary schools. *Research and Practice in Technology Enhanced Learning*, *12* (1), article 6.

White, R., & Gunstone, R. (1992). *Probing understanding*. London; New York: Falmer.

Yeung, P. M., Lee W.F., Wong K.Y., & Wong P.M. (2013). Learning diversity at NSS level: A preliminary study. *Hong Kong Teachers' Centre Journal Volume, 12*, 49-87.

Yeung, Y. Y, Lee, Y. C., & Lam, I. C. M. (2012). Curriculum reform and restructuring of senior secondary science education in Hong Kong: Teachers' perceptions and implications. *Asia-Pacific Forum on Science Learning and Teaching, 13*(2), article 11.

Yeung, Y.Y., Wang, Y., Lee, L.H., Lee, H.C., Chan, K.C.K. & Cheang, F.C.C. (2019). Educational use of an innovative mobile logger and evaluation of students' learning effectiveness in STEM education. In J. Theo Bastiaens (Ed.), *Proceedings of EdMedia + Innovate Learning* (pp. 261-

267). Amsterdam, Netherlands: Association for the Advancement of Computing in Education (AACE).

*Yousefzadeh, M., & Salimi, A. (2015). The effect of flipped learning (revised learning) on Iranian students' learning outcomes. *Advances in Language and Literary Studies*, *6*(5), 209-213.

*Zainuddin, Z. (2018). Students' learning performance and perceived motivation in gamified flipped-class instruction. *Computers and Education, 126*, 75-88.

Zainuddin, Z. H., & Halili, S. (2016). Flipped classroom research and trends from different fields of study. *International Review of Research in Open and Distance Learning, 17*(3), 313-340.

Zainuddin, Z. K., Haruna, H., Li, X., Zhang, Y., & Chu, S. (2019). A systematic review of flipped classroom empirical evidence from different fields: What are the gaps and future trends? *On the Horizon, 27*(2), 72-86.

Zhang S. (2018). *A systematic review and meta-analysis on flipped learning in science education* (Unpublished master's thesis). The University of Hong Kong, Hong Kong SAR, China.

Zimmerman, B. J. (2002). Becoming a self-regulated learner: An overview. *Theory Into Practice, 41*(2), 64-70.

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