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A review of the literature on flipping the STEM classroom: Preliminary findings

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This study analyses fifty-eight peer reviewed research studies on flipped learning in the higher education STEM disciplines. The review aims to continue on from other meta-analyses and identify themes from the literature, both positive and negative, in terms of perception, engagement and achievement. Two other themes are discussed, the self-efficacy of students and the development of graduate attributes beyond discipline knowledge. The review concludes that there has been a large increase in empirical research on flipped approaches to teaching and learning in the STEM disciplines and the findings are overwhelmingly positive.

Keywords: STEM, Flipped Learning, Flipped Classroom, literature review

Introduction

From its humble beginnings in 2000 when the term ‘inverted classroom’ was first coined by Lage, Platt and Treglia, through its more popular embodiment based on the work of two high school chemistry teachers (Bergmann & Sams, 2007), the term Flipped Learning is now embedded in the vocabulary of the higher education landscape, with a Google Scholar search currently returning over 64,000 hits. Some academics and administrators have embraced this approach to learning, others are maintaining the status quo until enough evidence is provided to ensure such changes will bring about improvement of student learning.

> Flipped Learning is a pedagogical approach in which direct instruction moves from the group learning space to the individual learning space, and the resulting group space is transformed into a dynamic, interactive learning environment where the educator guides students as they apply concepts and engage creatively in the subject matter (Flipped Learning Network, 2014).

There is certainly a change from a didactic ‘telling’ and passive ‘listening’ approach to more active student-centred learning approaches and this can (and ought to) be supported by the teacher. This may mean that initial workload for the teacher is increased as they need to provide trigger materials for students to engage with, facilitate discussions, and guide groups to reach outcomes. However, “Removed from the constraints of ‘providing content’, instructors can add value to the classroom experience by teaching students how to reason through problems and apply information to real-life issues.” (Rotellar & Cain, 2016, p. 1).

Focus on STEM

STEM (Science, Technology, Engineering and IT) has been chosen as a focus for this review due to the nature of the disciplines taught under this umbrella. Many STEM subjects contain an abundance of principles and (seemingly) abstract concepts which students need to ‘know’ before being able to move on to more practical, authentic applications. There is often a perceived need (by both teacher and student) for the teacher to personally deliver this content (Missildine, Fountain, Summers, & Gosselin, 2013). Bates and Galloway (2012) found that “In STEM subjects, and indeed many others, lectures are still a major component of most undergraduate courses. They are efficient but not particularly effective vehicles for promoting deep student learning” (p.1). Another misconception linked to the need to deliver content is that content needs to be removed from the curriculum in order to free up face-to-face class time to be active. Donovan and Lee (2015) found that sacrificing essential course content was not necessarily required in their food science class. Students who did not understand a concept were able to review the course in their own time and come to class prepared with questions to deepen their understanding. Li, Jiang, Li and Liu, (2016) found that more content could be covered in a flipped style of teaching (of computer-aided landscape design), as students were doing more outside the classroom. Yelmarthi and Drake (2015) also found that more content was covered in comparison to a traditional (lecture) style class in a digital circuits (engineering) course.

Current literature reviews

A number of reviews of the flipped learning (FL) and flipped classroom (FC) literature have recently been published, see for example Rotellar and Cain (2016); Seery (2015); O'Flaherty and Phillips (2015); Bishop and Verleger (2013) and Hamden, McKnight, McKnight & Arfstrom (2013). One of the first meta-studies was conducted by Bishop and Verleger (2013) who carried out a systematic survey of the literature published up to 2012. At that time the authors concluded that most research was reporting only student perceptions. Twenty-two studies were included in their review. The more current literature reviews have gone beyond perceptions to measure learning outcomes. Twenty-eight relevant papers were reviewed by O'Flaherty and Philips (2015). They concluded that little robust evidence for improved outcomes were reported. Also that there was a lack of capacity within academic staff to design good learning experiences possibly due to a lack of pedagogical understanding. Also that there are few if any conceptual frameworks being utilised in the design of the FC. This review investigates whether there is now changed evidence of improved outcomes. The review of the Chemistry FC literature conducted by Seery (2015) follows on from that of O'Flaherty and Philips by stating one of its purposes was to further investigate the issue of academics needing more guidance in designing better FC experiences. Seery (2015) also found an over reliance on content delivery through recorded lectures offered as pre-work. Table 1 outlines why this study is needed, ties the aims to other studies on this topic and details the two research questions underpinning the review of the flipped classroom literature.

Table 1: Aims and research questions of this study

Aim	Rationale	Research Question
1. whether there is significant evidence of the success of flipped learning reported specifically in the STEM literature. Success is measured in terms of evidence of improved learning outcomes.	Other meta-analyses of the literature have attempted to report on flipped learning across all disciplines or single disciplines. Previous reviews report limited evidence of improved learning outcomes.	To what extent are student learning outcomes improved, through use of a flipped learning approach?
2. whether there are any findings relevant to flipped research in STEM that differ from more generalist reviews.	Seery's (2015) review of flipped chemistry literature found an over reliance on content delivery through recorded lectures offered as pre-work.	How are the findings in the flipped STEM literature similar or different to previous reported findings?
3. Whether there are gaps or findings in the literature that can direct future research on flipped learning.		

Method

This review of the flipped literature has been guided by some of the recent meta-studies, particularly that of O'Flaherty and Philips (2015) who conducted a thorough scoping review of articles published up to October 2014. In that review, a number of inclusion and exclusion criteria were identified. This review uses similar criteria, including: time period (2012 – 2016), language (English), type of research (original article in a peer reviewed publication), study focus (students in a higher education setting studying a STEM discipline, both undergraduate and postgraduate), and literature focus (the overall theme relates to the flipped classroom approach).

In addition, for each selected article meeting the above criteria, the following was also noted: the criteria used to judge success (or not), the technologies used (if any), the country of study (Figure 1), the STEM discipline (Figure 1), the theoretical underpinning, framework or approach used in the design of the flipped classroom, and the class size. The majority of studies were conducted in subjects with smaller class sizes, less than 150 students (n=52).

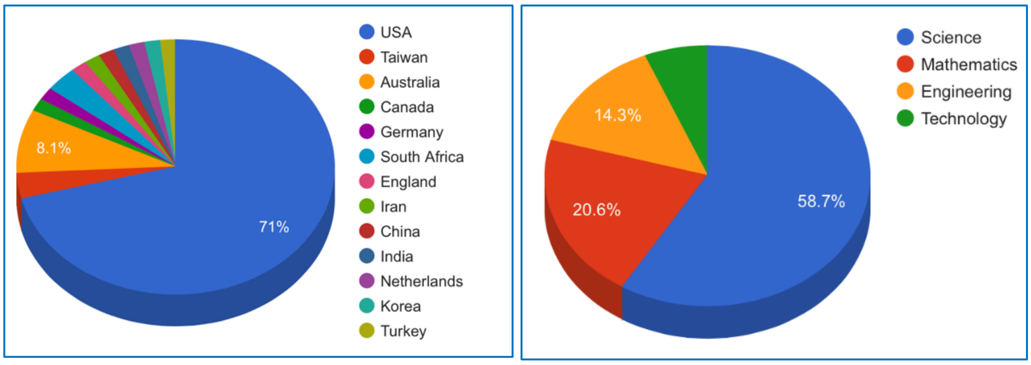

Figure 1: Distribution of studies in this review by country and by STEM discipline

Nine databases were searched in July 2016 using the criteria (flip* OR invert*) AND "higher education". The term STEM was not used as many papers did not identify to this keyword. The results were manually checked for STEM relevance and included if the discipline area was within STEM. The list is shown in Table 2 and includes information where a search may have been narrowed due to too many hits. Only full papers that were peer reviewed were deemed relevant to this study. As each relevant paper was found, it was logged in a spreadsheet with the associated criteria (as mentioned above). When papers were found that had already been listed these were not 'counted' as a relevant find. Hence the later database searches often returned nil results as all papers had already been logged. Table 2 outlines the databases in order of searching, search results and number of relevant articles recorded.

Table 2: Databases searched and relevant studies identified for this review

Database Searched	Search narrowed	Hits returned	Relevant articles
A+ Education		12	2
ProQuest		38	9
ERIC		63	5
British Education Index		62	0
Web of Science	'flipped' in title field only	120	27
Education Research Complete		215	3
Wiley		116	1
Academic Research Complete		50	0
Google Scholar	Included STEM but only chose top 100 results	100	11

A total of 58 articles were deemed relevant for this review, from the 776 articles found in the initial searches. The final item of note is the distribution of methods used for measurement, across the studies. Earlier reviews of the literature had noted few empirical studies had been used to measure outcomes (Bishop & Verleger, 2012 and later, O'Flaherty & Philips, 2015). This review found 15 studies used qualitative methods, eight studies used quantitative methods and 35 studies used mixed methods in their investigations and comparisons of flipped and traditional approaches.

Analysis

Each of the relevant papers was summarised and then content analysis was carried out using the manual extraction of themes (Saldana, 2013). Two cycles of coding were used, the first cycle using an Initial Coding method (Charmaz, 2014) whereby data was broken down across three categories, positive, negative and neutral. Reviewed studies tended to report findings in terms of the benefits (positive) and challenges (negative) of a flipped approach. The findings in some studies didn't identify to either positive or negative but were actually recommendations so these were grouped under the neutral category. In the second cycle, Focused Coding (Charmaz 2014) was used whereby the codes were arranged into themes. Table 3 shows the distribution of emerging themes across the three categories. Some of these will be described in the next section.

Table 3: distribution of emerging themes across three categories

Positive		**Negative**		**Neutral / Recommendations**	
Theme	*Number of studies coded*	*Theme*	*Number of studies coded*	*Theme*	*Number of studies coded*
*Achievement	39	*Lack of self-efficacy	11	Learning design	8
*Perception	33	Increased workload	9	*Perception	5
*Engagement	20	*Perception	7	*Self-efficacy	5
*Students' self-efficacy	12	Learning design	4	Video/resources	4
Learning design	2	Technology	3		
		*Achievement	2		

*themes discussed in the Findings section

Preliminary Findings & Discussion

Perception (of Flipped versus a traditional classroom setting), engagement and achievement are common measures in previous reviews (Bormann, 2014 as cited in Sohrabi & Traj, 2016). The findings from this review found similar themes and are described below, citing examples from the pool of 58 studies where relevant. *Note: Not all articles reviewed for this study are able to be cited due to length restrictions but will be available in a forthcoming publication.*

Achievement

Thirty-nine studies reported on achievement, mostly in terms of grades awarded. A few studies discussed achievement in terms of participation, for example how pre-work engagement (n=3) and active learning (n=3) were correlated with achievement. Fifteen studies reported that students achieved deeper learning through the flipped approach (Veeramani, Madhugiri, & Chand 2015) and this theme also covered the concept of student retention (n=5) (Yelamarthi & Drake, 2015). Ten studies found no statistical difference in the results between flipped and traditional approaches (Fitzgerald & Li, 2015). Heyborne and Perrett (2016) also found that there was no statistical difference (SD) in performance gains even though there was a gain in student perception (of learning). They said their study was limited due to small sample size (n=139). Another study which found no significant change concluded "…, students who have been successful already are likely to continue being successful whether in a traditional or flipped classroom" (Hotle & Garrow, 2015, p.10).

Only one study found poorer achievement (Bossaer et al., 2016) through use of a flipped approach. That study investigated examination results using analysis of covariance with prior academic performance variables (ie. GPA) as covariates. However, the control in that study was not a traditional lecture but an interactive lecture (use of case studies in the class combined with in-class polling or student response system, not solely a didactic lecture) therefore findings are open to interpretation. Bossaer et al., (2016) concluded that the lower performance in the flipped class was due to the lack of pre-class preparation accountability. Further evidence of the importance of the need for good design and alignment of the pre-class and the in-class activities (Khanova, Roth, Rodgers & McLaughlin, 2015).

Perception

Improving perceptions is important in the STEM disciplines because “[Flipped] courses are critical gatekeepers in potential STEM career pathways and are often very influential in student decisions about whether or not to pursue a STEM-related major.” (Love et al., 2013, p.323). A range of measurement techniques were used in the reviewed studies including various inventories, student feedback surveys and focus groups. Thirty-three studies reviewed for this paper found that students perceived the flipped teaching method positively. Concepts included in this theme included students taking a positive approach to learning (Long, Logan & Waugh, 2016), and ease of access to resources (Talley & Scherer, 2013). Negative perceptions were recorded in seven studies and the reasons stated varied. In some studies, students ‘longed for’ a return to the didactic traditional lecture and perceived they were not getting value for money unless they were receiving direct, live instruction from an expert (Mzoughi, 2015). In another study, students did not perceive any value from active learning “Students reported that the [flipped] approach required more work, and they did not seem to perceive the value of interactive learning approaches” (Missildine et al., 2013, p599). However, it must be remembered that student satisfaction is not necessarily an accurate indicator of learning (Benner et al., 2010 cited in Missildine et al., 2013). Another study that reported a decrease in initial perceptions of the flipped approach found that these perceptions changed over time of exposure to the flipped style of learning and students became more open to cooperative learning and innovative teaching methods. Initially they expressed frustration because their class time activities constantly changed and they were unprepared for this ‘unknown’ (Strayer, 2012). Other studies (n=7) reported a perception of increased student workload contributing to the negative perceptions towards a flipped approach (Khanova, Roth, Rodgers & McLaughlin, 2015; Hotle & Garrow, 2015).

Engagement

Twenty studies described how student engagement had improved through use of the flipped approach. Ten of these studies reported on the affordances and perceived value of interaction with peers, resources and teaching faculty which lead to increased engagement (McCallum, Schultz, Sellke & Spartz, 2015). Five studies detailed the face-to-face strategies such as in-class discussion and specifically working through problem solutions (Koo et al., 2016). However, some found that improved engagement did not always lead to improved achievement (Lucke, Dunn & Christie, 2016).

Self-efficacy

An interesting theme was identified across the three categories related to students’ sense of self-efficacy. Many studies (n=12) reported that students were positive about taking control of their learning through use of preparation resources (Koo et al., 2016) and development of new, independent learning strategies (McLean et al., 2016). There was division over whether the flipped approach was good (n=8) (Veeramani, Madhugiri, & Chand, 2015) or bad (n=7) (Persky & Dupuis, 2014) for first year cohorts or introductory/foundation courses. Yelamarthi and Drake (2015) found that whilst first year students struggled in the first few weeks, if they were supported through concept reinforcement during hands-on activities and timely feedback from the instructor, then in fact they *were* able to succeed in the flipped classroom.

Graduate attributes in STEM

Whilst this is not specifically a theme that emerged across the reviewed studies, it is noted her for its importance for future-focused learning. STEM students have a lot of content knowledge to remember and understand before they can move to higher order skills such as application and analysis. In McLean et al., (2016) students reported that they developed independent learning strategies, spent more time on task, and engaged in deep and active learning through the flipped approach. Whilst attainment in terms of marks is important to gaining qualifications, the development of attributes that go beyond discipline knowledge such as independent and lifelong learning, collaboration and communication skills are greatly valued in today’s workplace. “..student discomfort over the lack of in-class lecturing can give way to meaningful discussions about the nature of higher education and real progress toward guiding students to becoming self-regulating, lifelong learners” (Talbert, 2014). If the development of these attributes in STEM students is being encouraged as evidenced in this review, then this is indeed a win for this approach to learning and teaching.

Conclusions and further research

The preliminary findings of this review indicate mainly positive themes in the literature on flipped learning in the STEM disciplines. There has been an explosion of empirical studies measuring achievement of student learning outcomes in the STEM disciplines (published in 2015 and so far in 2016), the majority comparing flipped to traditional approaches to teaching. One important finding from this review indicates the importance of a flipped approach for improving students’ sense of self-efficacy. This is important in the current work-place climate where skills such as life-long learning and adaption to change are highly valued.

This review has indicated a few areas for future research. The majority of peer reviewed articles that fit the review criteria came from North America which leads to a particular cultural bias. Other areas for investigation could be gender bias in flipped (Ichinose & Clinkenbeard, 2016), differences in implementation and results of flipped approaches in large classes (Khanova et al., 2015), and more focus on flipped applications in engineering and IT subjects. There was only one longitudinal study (Benade & Callaghan, 2015) found for this review and in time, further studies of this nature will allow more robust conclusions to be made on the flipped approach.

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