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Technology-supported student interaction in post-secondary education: A meta-analysis of designed versus contextual treatments

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ABSTRACT

The present study extends the results of a larger meta-analysis that addressed the effects of technology use on student achievement and attitudes in postsecondary education. The focus of the current meta-analysis is the use of technology to enable instructional conditions that promote collaborative interactions among learners. More specifically, it aims to compare the impact of designed interaction treatments (i.e., collaborative activities intentionally built into course design) and contextual interaction treatments (i.e., course conditions that result in high levels of student–student interaction but are not intentionally designed to promote collaboration) on student learning outcomes. Results indicate that designed treatments outperform contextual treatments ($\bar{g} = 0.52$, $k = 25$ vs. $\bar{g} = 0.11$, $k = 20$, $Q_{Between} = 7.91$, $p < .02$) on measures of achievement, emphasizing the importance of planning and instructional design in technology integration in postsecondary education. The results are discussed in relation to the literature of student–student interaction and collaborative learning.

1. Introduction

This review extends a larger meta-analysis of the comparative effectiveness of technology integration in postsecondary education (Schmid et al., 2014). It uses a subset of research from the database of the original meta-analysis, but extends coding of selected study characteristics with the goal of clarifying and advancing some of Schmid and colleagues' major findings. In addition to establishing the fact that institutions of higher education continue to take advantage of developments in computer and communication technologies, as is reflected in the overall small but statistically significant average effect size, Schmid and colleagues studied various functions of technology use and found largely in favor of those instructional tools that provided students with cognitive support for learning. The current review takes a further step in exploring under what instructional conditions the use of various technological tools in postsecondary classrooms helps to achieve better educational outcomes. Specifically, it addresses the promising outcomes that arose from Schmid et al. (2014) with regard to the

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effects of technology in supporting communication and interaction among students. Additional study features coding and refined analyses were carried out to separate the influence of *designed* and *contextual interaction treatments* as they are facilitated by technology use. Several theoretical perspectives, briefly outlined in the upcoming sections, will help shape a rationale for this analytical approach by putting it into the context of educational research on student interaction and collaborative learning.

1.1. Theoretical perspectives

1.1.1. Student interaction in distance education

Regardless of a particular instructional delivery form, student interaction with instructors, other students, and content is widely regarded as fundamental in today's classrooms. The importance of these three types of interactions has been particularly recognized in various theoretical frameworks on distance and online education because of the separation in space and/or time of students from their teachers and peers (Anderson, 2003; Beldarrain, 2006; Moore, 1989). This separation in distance education demands the use of either asynchronous or synchronous technology for students and teachers to interact and subsequently collaborate. The importance of student–student interaction has been demonstrated in several topical meta-analyses. In examining undergraduate distance education courses, Lou, Bernard, and Abrami (2006) found a link between student–student interaction and greater achievement success ($\bar{g} = 0.11$, $k = 30$, $p < .05$). Furthermore, student–student interaction was found to be a significant predictor of student achievement in multiple meta-regression ($R^2 = 17.97\%$ of total variance accounted for). Later, in a more direct test of the three kinds of interaction treatments (i.e., student–student, student-teacher, and student-content), Bernard et al. (2009) demonstrated an explicit link between interaction and academic performance in distance education. All three forms of interaction treatments were found to positively and significantly improve learning, with student–student interaction being the most important among the three ($\bar{g} = 0.49$, $k = 10$, $p < .05$).

Nevertheless, the likely assumption among educational practitioners that providing students with opportunities to interact with each other will automatically translate into successful collaboration has not been supported by research findings. Referring to findings from the meta-analysis just described, Abrami, Bernard, Bures, Borokhovski, and Tamim (2011) remarked:

[J]ust because opportunities for interactions were offered to students does not mean that students availed themselves of them, or if they did interact, that they did so effectively. The latter case is the more likely event, so the achievement effects resulting from well-implemented interaction conditions may be underestimated in our review (p. 86).

The validity of the above argument was further investigated by Borokhovski, Tamim, Bernard, Abrami, and Sokolovskaya (2012) by selecting student–student interaction studies from the original meta-analysis (Bernard et al., 2009) and assessing them on markers of collaborative activities. The hypothesis was that enhanced learning would occur in distance education contexts if instructional strategies were set up to maximize student–student interaction to enable collaboration (i.e., *designed interaction treatments*). Contrasted with these treatments were conditions where the context of instruction (whether technological or organizational) simply provided students with opportunities to interact without any intentional efforts to introduce elements of collaboration in the course design (i.e., *contextual interaction treatments*). Specifically, Bernard et al. (2009) used Moore's (1989) distinction among three types of interaction in distance education (i.e., student-teacher, student-content, and student–student) to test the related hypothesis about the joint effects of their various combinations (Anderson, 2003). Special attention was paid to student–student interaction, understood as communications among individual students or among students working in small groups. In the context of modern distance education, student–student interaction, enriched by technology, may occur either synchronously (e.g., video-conferencing) or asynchronously (e.g., discussion boards), but almost inevitably has an impact on student cognition and motivation (e.g., Abrami et al., 2011; Kanuka & Anderson, 1999). Borokhovski et al. (2012) further defined *designed* and *contextual interaction treatments*, respectively, as: (1) intentionally planned and implemented collaborative instructional activities that are intended to increase student learning; and (2) instructional settings that contain the necessary conditions for student–student interaction to occur, but are not intentionally designed to create collaborative learning environments.

More elaborate coding, designed to capture relevant study characteristics, and subsequent analyses revealed significant average effect sizes for both types of interaction treatments (i.e., $\bar{g} = 0.50$, $k = 14$, $p < .01$ and $\bar{g} = 0.22$, $k = 22$, $p < .05$ for designed and contextual, respectively). More importantly, *designed interaction treatments* significantly outperformed *contextual interaction treatments* ($Q_{Between} = 6.37$, $p < .01$), thus supporting the hypothesis that instructional design and planning encourage students to avail themselves of the opportunity to interact and collaborate more effectively and productively. A question remains, however, as to whether these conditions that manifested themselves in the context of distance education, given the overall importance of interaction there, also apply to classroom technology integration.

1.1.2. Technology-supported student interaction in postsecondary education

The case for distance education is compelling because interaction and collaboration are highly dependent on the use of technology, which is not as true for face-to-face postsecondary education contexts. While technology use within classroom instruction may enhance certain aspects of the learning process, its presence is much less of a necessity for ensuring interaction and collaboration. With this in mind, the question is whether the notion of technology-supported student–student interaction, drawn from the distance education literature, carries over into face-to-face instructional settings. Some evidence is provided by Fjermestad (2004), who analyzed 145 experiments investigating synchronous and asynchronous communication modes over a span of 20 years. Results demonstrated that group-support systems have positive impacts on decision quality, depth of analysis, equality of participation, and student satisfaction. However, the review did not address the relationship between technology-supported group-based activities and student achievement.

Earlier, a similar question was addressed in a meta-analysis by Lou, Abrami, and D'Appolonia (2001) synthesizing empirical research on the effects of small-group versus individual learning with technology. The results of that meta-analysis revealed, among other things, a significant but not overly large average effect size ($\bar{g} = 0.15$, $k = 486$, $p < .05$) in a combined collection of pre-K-12 and college students. Surprisingly, the results did not differentiate across grades levels—elementary, secondary, and postsecondary students were relatively the same on achievement outcomes.

More recently, Schmid et al. (2014) examined studies of technology integration with students in postsecondary classroom settings only (i.e., no distance education). They decided to make the degree of technology use the effect size defining characteristic so that instructional conditions judged to utilize more technological tools and/or more advanced (i.e., richer in functionality) educational technology more frequently and/or for longer periods of time were designated as treatment or experimental conditions, whereas instructional conditions characterized by lesser degrees of technology use served as control or comparison groups consistently across all included studies. As such, the main question of that large-scale meta-analysis was about the added value of technology use for student learning, which was answered positively ($\bar{g} = 0.27$, $k = 879$, $p < .05$), while acknowledging the large variability that surrounded the average effect size. Among other things, Schmid et al. (2014) found that higher levels of *student–student interaction* (i.e., defined and coded the same way as in Bernard et al., 2009, in the context of distance education) in the treatment condition, compared to the control condition, resulted in higher achievement effect sizes (see Table 1). In this study, since the treatment-defining characteristic was more technology in the treatment versus less in the control, the presence of technology appears to have facilitated or at least improved the effectiveness of interaction among students, as reflected in achievement learning outcomes.

1.1.3. Student collaboration

Student–student interaction, by itself, is not necessarily an educational activity, nor does it always result in positive educational outcomes. Kirschner and Erkens (2013) put it this way: “It has become clear that simply placing learners in a group and assigning them a task does not guarantee that they will work together … coordinate their activities … engage in effective collaborative learning processes … participate in argumentative discussions … or lead to positive learning outcomes (p. 1).” Interaction becomes purposive when small-group student activities are structured and facilitated in such a way that cooperation and collaboration become the primary raison d'être of small-group interaction. *Collaborative learning* refers to specific forms of interaction that have a purposive intent and a general set of structural elements to facilitate it (e.g., Harasim, Hiltz, Teles, & Turoff, 1995). Collaborative learning has been the subject of some debate, particularly as it is distinguished from cooperative learning (Bruffee, 1995; Johnson & Johnson, 2007), which tends to be more structured, procedural, and demanding of teacher involvement. However, it is not unusual to find the two learning approaches conflated in spite of arguments that cooperative and collaborative learning are at odds with one another in several fundamental ways (Bruffee, 1995). For the purposes of the current review we do not distinguish between these two terms, but continue using them jointly to address the next question of interest: Does designing and implementing cooperative/collaborative activities add value to student learning outcomes when educational technology is used in postsecondary classrooms?

1.2. Meta-analyses of collaborative learning research

Over the past 15 years, at least seven meta-analyses have been conducted to determine the effects of collaborative and small-group instruction on achievement outcomes as summarized in Table 1. Lou, Abrami, and D'Appolonia (2001), the meta-analysis with the widest span in terms of participant age, found a small but significant overall average effect size, though no difference between younger and older learners. Three meta-analyses examined the effects of collaborative learning with K-12 learners (Puzio & Colby; Williams; Wright et al.). Average effect sizes ranged from 0.16 (Puzio & Colby) to 0.80 (Williams). The two results for postsecondary education alone were dramatically different (Springer et al., 0.51; Tomcho & Foels, 1.14). One

Table 1
Seven meta-analyses of collaborative learning and small-group research (achievement outcomes) over the past 15 years, ordered by year of publication.

Meta-analyses (Year)	*K*	Average *ES*	Learning Configuration	Subject matter	Level of learners	Technology	Inclusive dates
Springer, Stanne, and Donovan (1999)	49	0.51	Small-Group Learning	STEM	Postsecondary education	No	1980–1999
Lou et al. (2001)	486	0.15	Small-Group Learning	Various	preK-12, College	Yes	1990s
Williams (2009)	20	0.29	Collaborative Learning	Various	K-12	Yes	1999 and later
Tomcho and Foels (2012)	37	1.14	Collaborative Learning	Psychology	College	No	1974–2011
Puzio and Colby (2013)	16	0.16	Collaborative & Cooperative Learning	Literacy	K-12	No	30 years of research
Wright et al. (2013)	16	0.80	Collaborative Learning	Various	K-12	Yes (1 study)	1996–2005
Wecker and Fischer (2014)	17	0.00–0.22	Collaborative Learning (argumentation)	Content specific knowledge	Various	Yes (CSCL)	1975–2005

meta-analysis examined a particular collaborative strategy, argumentation (Wecker & Fischer), and found average effect sizes to be low, ranging from 0.0 to 0.22.

The current study will add some clarity to this literature, particularly in postsecondary education, as it reaches beyond the overall effect of collaborative learning on student achievement to examine whether there is an added value in planning for interaction and collaboration (i.e., *designed interaction treatments*) versus what Kirschner and Erkens (2013) refer to as grouping students with no plan (i.e., *contextual interaction treatments*). Also, since this study is so similar in intent and procedures to the meta-analysis of distance education by Borokhovski et al. (2012), it may be of interest to compare the findings of these two studies to see whether there are differences between *designed interaction treatments* in distance education and face-to-face learning contexts.

1.3. Review objectives

The current project aims to explore the effect of planned collaborative learning setups that are hypothesized to support student–student interactions beyond what is incidentally enabled by technology use in postsecondary classroom instruction. It employs the same theoretical framework and analytical approach previously used to assess the relative effectiveness of *designed* and *contextual* interaction treatments in distance education (Bernard et al., 2009; Borokhovski et al., 2012). *Designed interaction treatments* are defined as intentionally implemented pedagogical setups for implementing collaborative learning which are meant to increase student achievement. Alternatively, *contextual interaction treatments* refer to learning settings that contain the necessary conditions for student–student interaction to occur, but are not intentionally designed to create collaborative learning environments.

In this paper, we present and discuss the results comparing these two types of interaction treatments in application to technology-enhanced classroom learning in postsecondary education. Thus, we bring together the two theoretical perspectives discussed earlier (Section 1.1.) in a comparison between *designed interaction treatments* (i.e., interaction plus collaboration) and *contextual interaction treatments* (i.e., interaction without explicit collaboration). The meta-analysis then proceeds further to investigate the nature of the most effective interaction treatments through moderator variable analysis (i.e., instructional and demographic study features).

2. Method

2.1. Schmid et al. (2014)

As stated previously, this study follows from a large-scale meta-analysis of the effectiveness of technology-enhanced instruction in postsecondary education (Schmid et al., 2014) using its set of included studies as the data source. The main purpose of that original systematic review was to examine the achievement effects of computer-based technology use in postsecondary education classrooms, where experimental conditions (higher in degree of technology use) were compared to control conditions (lower in degree of technology use, including technology-free educational settings). Educational technology was defined broadly in accordance with the definition suggested by Ross, Morrison, and Lowther (2010) as "… a broad variety of modalities, tools, and strategies for learning, [whose] effectiveness, therefore, depends on how well [they] help teachers and students achieve the desired instructional goals" (p. 19) to include all types of computer-based tools and applications used by either teachers or students to support learning, but not for administrative purposes (e.g., grading, keeping and managing records). Schmid et al. (2014) provided a very detailed description of the methodology they employed at all stages of their meta-analysis. Here we will simply summarize the original meta-analysis method as follows.

Extensive literature searches were designed and conducted to identify and retrieve primary empirical studies relevant to the major research question. In addition to searches in more than 10 electronic databases (e.g., ERIC, EdLib, Education Abstracts, Medline, ProQuest Digital Dissertations & Theses, PsycINFO, British Education Index), branching from previous relevant reviews and tables of content for major educational journals was performed, as well as manual Google Internet searches, including searches for various conference proceedings. A set of inclusion criteria dictated the study characteristics required to retain studies for inclusion. Studies were required to:

- be published no earlier than 1990 and be publicly available (or archived);
- address the impact of computer-based technology on student achievement, as reflected in any objective measure, standardized or otherwise, either teacher/program-designed or prepared by researchers (e.g., final exams, cumulative posttest scores);
- contain at least one between-group comparison where one group is considered the experimental condition (i.e., higher degree of technology use) and the other group the control condition (i.e., lower degree of technology use, including technology-free settings);
- be conducted in a formal postsecondary education setting;
- represent classroom or blended instruction, but not distance education environments; and
- contain sufficient statistical information for effect size extraction.

All stages of the review and data extraction that preceded the analytical stage, namely (1) study screening and selection, (2) effect size calculation, and (3) study feature coding, were completed in both meta-analyses by two researchers working independently and meeting to discuss and resolve conflicts, if any. For instance, when evaluating the degree of student–student interaction in both instructional conditions, reviewers independently answered the following question: Did students in the experimental group interact or have opportunities to interact more, about equally, or less than their counterparts in the control condition? Their initial responses were compared and rare cases of discrepancies were resolved through the joint discussion, inviting a third opinion if necessary. As a result, all studies in the original collection (Schmid et al., 2014) were classified into three uneven categories: (1) the experimental group is higher than the control group in opportunities for student–student interaction; (2) both groups are about the same in opportunities for student–student interaction; and (3) the control group is higher than the experimental group in opportunities for student–student interaction. Only studies from the first category were under consideration in the current meta-analysis, where they were further sorted as featuring either *designed* or *contextual interaction treatments*. For example, in the study by Liu, Lin, and Chu (2007), students in the experimental condition studied introductory-level physics using a treatment referred to as Interactive Response System (IRS), whereas control students largely relied on conventional lectures. There could be little doubt that the IRS has higher potential than a lecture alone for enabling and supporting student–student interaction: "… IRS is known as a simple and convenient technology-enabled learning environment for enhancing classroom interaction" (Liu et al., 2007, p. 6237). However, our reviewers found no explicit indication that the IRS-based activities were specifically planned, structured, or implemented with the goal of promoting collaborative work among students. Because of it, the student–student interaction treatment in this study was judged to represent the *contextual* type (i.e., interaction that lacks designed collaborative qualities).

Study feature definitions were derived from the theoretical and empirical literature in the field, and their coding was based on previous meta-analyses (Bernard et al., 2009; Schmid et al., 2014). These coded study features were of the following major types:

- publication variables (e.g., date of publication);
- methodological study features included research design (randomized control trials or quasi-experiments), type of outcome measure (cumulative measures of academic performance, e.g., final exams or composites of several complementary measures, e.g., projects, assignments), precision of the effect size extraction procedure (calculated from exact descriptive and inferential statistics or estimated based on partially reported data) and material equivalence (same or different);
- major purpose of technology use (i.e., support for communication, information access, presentation, and cognitive support as defined in Schmid et al., 2014);
- substantive instructional variables, including decisions to use elements of blended learning (i.e., up to 50% of instructional time spent on out-of-class activities);
- demographics (e.g., student grade level) and academic descriptive variables (e.g., subject matter).

For the purposes of the current project, the focus was on the instructional moderator variables that may affect student–student interaction in experimental groups in comparison with the control groups. However, some of the major findings of the larger meta-analysis, especially with respect to the overall effect size and other instructional study features, will help contextualize the current study.

Cohen's d effect sizes (i.e., $d = \overline{X}_E - \overline{X}_C / SD_{Pooled}$) were extracted from included studies for available independent comparison and then converted to Hedges' g (i.e., small sample bias correction) as follows (Hedges & Olkin, 1985):

$$g \cong d\left(1 - \frac{3}{4N - 9}\right)$$

At the synthesis stage, independent effect sizes were weighted using random effects inverse variance weights to derive the overall average effect size as an estimate of the influence of educational technology use on student achievement outcomes. The fixed-effect model was used to estimate heterogeneity of the distribution of effect sizes, and then moderator variable analyses were performed using the mixed-effect model (e.g., Borenstein, Hedges, Higgins, & Rothstein, 2009).

After exclusion of outliers and studies with inadequate methodological quality, the final set of 673 studies yielded 879 independent effect sizes. The weighted average effect size of $\overline{g} = 0.27$ was significantly different from zero with a moderate level of heterogeneity. Moderator analyses revealed that the major purpose of technology use was a significant factor, whereby cognitive support tools (predominantly in the hands of students) produced the highest weighted average effect size of $\overline{g} = 0.36$ ($k = 187$), followed by communication support with a $\overline{g} =$ of 0.24 ($k = 27$), while support for presentation and delivery (almost exclusively teacher-used) resulted in the weakest $\overline{g}$of 0.15 ($k = 113$).

More importantly, moderator variable analysis addressing student–student interaction revealed significant findings in favor of higher student–student interaction treatments. Those results are summarized in Table 2.

Table 2
Mixed effects analysis of the degree of student–student interaction treatments in the experimental and control conditions (Schmid et al., 2014).

Levels of S–S interaction	*k*	$\bar{g}$	*SE*	95th Interval		*Z*-value	$Q_{Between}$
				Lower	Upper		
Treatment & Control equal	703	0.29	0.02	0.25	0.33	15.16*	
Control higher	127	0.16	0.04	0.07	0.24	3.51*	
Treatment higher[1]	47	0.36	0.07	0.22	0.49	5.07*	
Between groups ($df = 2$)							9.35**

*$p < .001$; **$p = .009$. Post hoc test: Treatment higher > treatment and control equal and control higher.

2.2. Current study

From the entire collection of studies in the original meta-analysis, all those including experimental conditions with higher interaction than the control conditions were selected for the current follow-up analysis and synthesis. This resulted in 47 independent effect sizes from 40 studies with a total of 5381 participants. Additional coding was conducted to separate the studies into two meaningful categories: *contextual* and *designed interaction treatments*. They were defined as follows:

- *Contextual interaction treatments*, where the context of the experimental group allowed for more interaction among the students by providing more options and alternatives for communication through the affordances of the technological tools used. For example, in the study by Faul, Frey, and Barber (2004), a Web-assisted *Blackboard* environment featured various interaction-enabling options, but was used by students at their own discretion, unguided by any specific instructional design; and.
- *Designed interaction treatments*, which are pedagogy–driven interactions where the reported course design in the experimental group allowed and enabled higher student–student interaction with the support of the technological tools used. These could be predominantly technology-based, such as in Hwang, Wang, and Sharples' study (2005), where a Web-based tool was available to students, which was designed specifically for creating and sharing written annotations of each other's work. On the other hand, *designed interaction treatments* could be in the form of organized in-class activities. The study by Lane and Aleksic (2002) provides a good example of such settings. There, students worked in computer labs in collaborative learning groups, and their performance was evaluated according to principles of positive interdependence and individual responsibility (see the Appendix for a detailed summary of all studies in the category of *designed interaction treatments*).

Three reviewers worked independently to complete the coding of all selected studies to decide whether the experimental condition of each study fell into either *contextual* or *designed interaction treatments*. Decisions were based on explicitly reported study characteristics indicating the presence of course design aspects that allow for the occurrence of student collaborative work. One study (Nowack, Watt, & Walther, 2009) that had yielded two independent effect sizes was removed from the original 2014 collection because the treatment and control conditions were too similar with regard to instructional design. The average pairwise agreement rate on the initial coding was 80.5% (Cohen's kappa = 0.61). Seven disagreements were resolved through joint discussions among the three reviewers. In all, 24 studies ($k = 25$) were categorized as containing *designed interaction treatments* and the remaining 15 studies ($k = 20$) were categorized as containing *contextual interaction treatments*.

Fig. 1 illustrates the process of selecting studies from the Schmid et al. (2014) collection for the purposes of this meta-analysis.

3. Results

3.1. Preliminary analysis

Publication bias analysis and sensitivity analysis are two important preliminary steps usually undertaken to ensure that the results of a meta-analysis are not biased (Bernard, Borokhovski, Schmid, & Tamim, 2014). Publication bias analysis is intended to estimate whether a large set of studies that might nullify the results of the meta-analysis have not been found or, conversely, whether there is a reasonable balance of positive and negative (or high and low) effect sizes surrounding the average effect size. Since journals tend to publish more positive than negative findings (i.e., Polanin, Tanner-Smith, & Hennessy, 2015), this analysis is conducted to ensure that there is roughly equal representation around the average effect size. Examination of the symmetry of a funnel plot (i.e., sample size by effect size) and the interpretation of various statistical procedures (e.g., Duval & Tweedie's Trim and Fill; Duval & Tweedie, 2000) and tests (e.g., Orwin's Classic Failsafe *N*; Orwin, 1983) can help determine if there is selectivity in the studies that are included in a meta-analysis.

Sensitivity analysis asks the question: Are there overly large or overly leveraged effect sizes that can bias the average effect size either positively or negatively? Leverage here refers to studies with large samples whose positive or negative effect sizes reside at the upper or lower extremity of the collection of studies. Sensitivity analysis is often investigated using a “one study

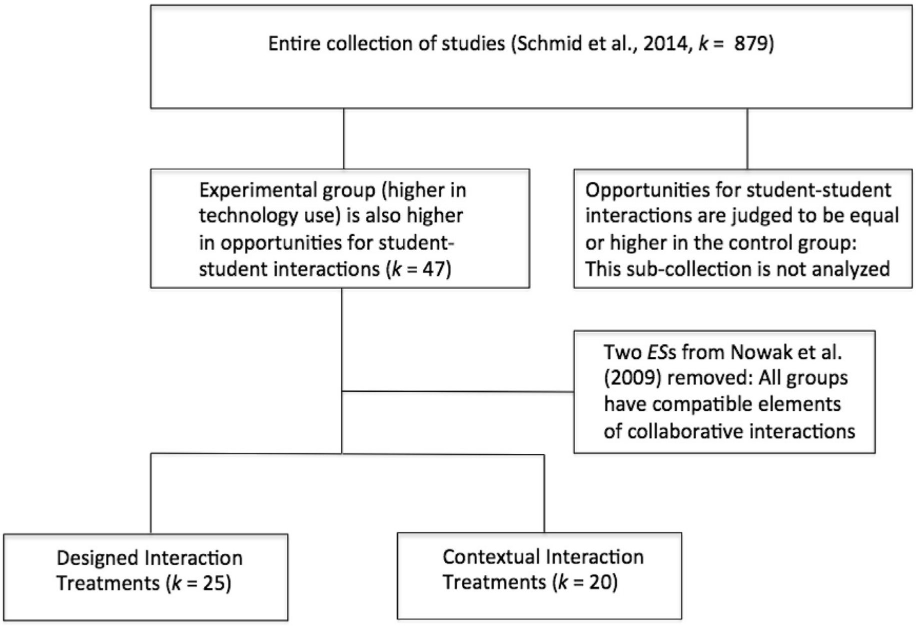

Fig. 1. Flow diagram of the process of selecting studies.

removed" procedure whereby each study is removed, in turn, and the average effect size and standard error recalculated to determine which, if any, studies have undue positive or negative influence on the findings.

For the current meta-analysis, these procedures were applied during the process of analyzing Schmid et al. (2014), and so the original study is considered to be free of publication bias and effect/sample size anomalies.

Since this collection represents a smaller selection of studies from the larger meta-analysis, it is possible that publication bias could occur, even though it was not present there (Schmid et al., 2014). For that reason, we conducted a separate analysis for this study using 45 independent effect sizes drawn from 40 studies. The funnel plot is shown in Fig. 2. Essentially, it describes a balanced distribution around the fixed effect average effect size and a slightly imbalanced distribution under the random effects model. The imputation of two additional studies on the negative side of the distribution would change the weighted average from $\overline{g} = 0.35$ (Table 3) to $\overline{g} = 0.34$.

3.2. Primary analysis

The primary analysis is shown in Table 3. The overall weighted random effect is $\overline{g} = 0.35$ after two effect sizes extracted from the Nowack et al. (2009) study were removed. The lower pane of Table 3 shows the distinction between *designed interaction* and *contextual interaction treatments*. These results indicate two things: (1) the average effect size for *designed interaction treatments* of $\overline{g} = 0.52$ is significantly different from zero while that of *contextual interaction treatments* is not ($\overline{g} = 0.11$); and (2) the average effect size for *designed interaction treatments* differs significantly from that of *contextual interaction treatments*. The last line in the table indicates that the overall distribution of 45 effect sizes is heterogeneous beyond the level of chance. The I^2 of 77.71% is indicative of moderately high heterogeneity.

Table 4 below shows the distribution of studies between levels of methodological study quality across the two types of treatments. These methodological study features revealed no statistically significant differences across the two levels of the primary moderator variable, *designed* and *contextual interaction treatments*.

3.3. Moderator variable analysis

Only one of the coded substantive moderator variables (Table 5) produced a significant difference across its levels. The others, grade level, subject matter, and degree of blending, were not significant.

The one significant moderator variable, *major function of technology*, mirrored the results of Schmid et al. (2014) by finding that within the 25 *designed interaction treatments*, *cognitive support* outperformed *communication support* and a category of mixtures. This finding suggests that tools supporting student cognition are more effective than other technology uses.

4. Discussion

Fundamentally, this study is about the use of technology in postsecondary education classrooms, as it relates to support for student–student interaction and collaboration, and its effect on achievement outcomes. The meta-analysis found 45 effect

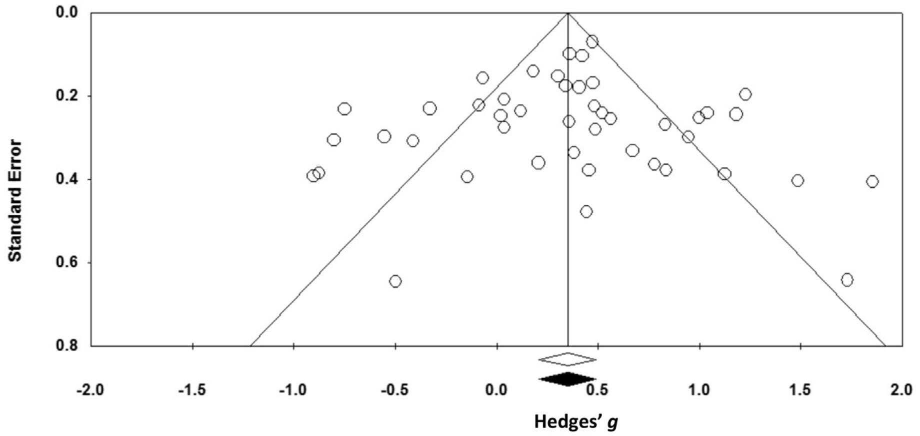

Fig. 2. Funnel plot (standard error by g) of the random ($\bar{g}$: clear) and fixed models ($\bar{g}$: black).

Table 3
Mixed effects analysis of *designed* versus *contextual interaction treatments*.

Levels of interaction treatments	k	$\bar{g}$	SE	95th Interval		Z-value	$Q_{Between}$
				Lower	Upper		
Random Effects Model							
All interaction treatments	45	0.35	0.07	0.21	0.49	4.90**	
Mixed Effects Model							
Designed interaction treatments	25	0.52	0.08	0.36	0.68	6.53**	
Contextual interaction treatments	20	0.11	0.12	−0.14	0.35	0.85	
Between, $df = 1$							7.91*
Heterogeneity analysis[a]	$Q_{Total} = 197.44$ ($df = 44$), $p < .001$				$I^2 = 77.71$	$\tau^2 = 0.15$	

[a] Based on the fixed effect model. *$p < .020$**$p < .001$.

Table 4
Frequencies by treatment of methodological quality study features.

Levels of methodological quality study features	*Designed Interaction Treatments* ($k = 25$)	*Contextual Interaction Treatments* ($k = 20$)
Research Design		
Randomized Experiments (RCTs)	9 (36%)	10 (50%)
Quasi-Experiments (QEDs)	16 (64%)	10 (50%)
Outcome Measure Type[a]		
Cumulative Final Grade	15 (60%)	17 (85%)
Average or Composite Grade	10 (40%)	3 (15%)
ES Extraction Procedure		
Calculated ES	18 (72%)	13 (65%)
Estimated ES	7 (28%)	7 (35%)
Material Equivalence[b]		
Same materials	24 (96%)	19 (95%)
Different materials	0 (0%)	0 (0%)

[a] Consists predominantly of teacher-made instruments (only one of the measures is standardized).
[b] Does not add up to the respective totals as one study in each category did not provide sufficient information to confidently code for Material Equivalence.

Table 5
Mixed effects moderator variable analysis for major functions of technology.

Levels	k	$\bar{g}$	95th Interval		$Q_{Between}$
			Lower	Upper	
Cognitive support (CS)	5	0.63*	0.39	0.86	
Communication support	8	0.32*	0.13	0.51	
Mixed (presentation support + CS)	6	0.14	−0.14	0.41	
Between groups, $df = 2$					7.56, $p = .02$

*$p < .05$. Note: The number of cases does not add to $k = 25$ because levels with $k < 5$ were excluded from the analysis.

sizes where technology use was associated with higher levels of student–student interaction in the experimental condition. Twenty-five of these involved some form of planning and design for the use of technology to support and promote collaborative work (i.e., *designed interaction treatments*) and 20 showed that clear evidence of planning for collaboration was absent (i.e., *contextual interaction treatments*). We found that the average weighted effect sizes of these two collections differed significantly (i.e., $\overline{g} = 0.52$, $k = 25$ vs. $\overline{g} = 0.11$, $k = 20$, $Q_{\text{Between}} = 7.91$, $p < .02$).

This primary finding of the meta-analysis suggests that collaborative qualities purposefully added to technology-supported student–student interaction substantially add to learning. Consequently, we judge instructional design that supports pedagogically sound planning and the implementation of collaborative activities to be the clear winner. When educational practitioners strive to effectively achieve their instructional goals, simply relying on more interactive technological tools is not enough—special attention should be paid to how to maximize their potential by designing tasks and activities that would elevate interaction to the stature of collaboration.

Within the group of *designed interaction treatments*, we asked the additional question: Do the ways that technology is designed to function, related to student–student interaction, differ when they are compared? The answer to this more nuanced question appears to be "yes," especially when technology is used by students to support cognitive processes (i.e., cognitive tools). Communication support was also found to be significant, but typically implicates fewer design features. Thus, we focused on the pedagogical implications derived from studies involving students interacting with content, peers, and instructors (including when cognitive tools are used).

The major challenge we faced when attempting to derive useful design recommendations was the difficulty in developing a more specific and standardized definition of *designed interaction treatments*. The problem was likely exacerbated by the relative paucity of studies in this area and the lack of explicit descriptions of instructional interventions in them. The treatments varied widely, as evidenced by their accounts summarized in the Appendix and the large between-study variability indicated by Q_{Total} in Table 3 (Section 3.2.). The lack of studies may also have contributed to our inability to find significant differences between levels of several moderators. Greater power to find differences would have been an asset in this meta-analysis. Finally, even though highly trained and extremely experienced coders were used to establish the distinction between the treatment group and the control group, and our inter-rater reliabilities are sufficiently high, this is a form of coding known as high inference (Cooper, 2010). It is the most difficult and most error-prone coding there is, and so it is possible that some error was introduced in the coding process. Reversals of this distinction, however, would likely have produced more conservative results.

Similar concerns apply to defining and analyzing the effects of cognitive tools as one of the most influential moderators. The primary way that applications in these studies differ from the classical definition of cognitive tools as "… computer-based applications that are normally used as productivity software" (Jonassen, 1995, p. 40) is that they are used jointly and collaboratively to solve problems, engage in critical thinking, analyze data, or otherwise create knowledge. Student achievement will be most positively affected by interactions that involve these types of activities. Kim and Reeves (2007) describe the "partnership" that exists between a student and a cognitive tool and also a joint learner system that may include other students working collaboratively with the technology. This collaborative effort, among students and between students and the tool, most likely represents best practices from both a cognitivist and a constructivist perspective. Iiyoshi, Hannafin, and Wang (2005) describe a classification structure for cognitive tools that includes five categories: information seeking, information presentation (i.e., aid to student presentation), knowledge organization, knowledge integration, and knowledge generation. It is unlikely that all of these functions could be successfully integrated into one tool, but it is entirely possible that multiple tools could be used to extend a group's cognitive functioning. For example, Mantri, Dutt, Gupta, and Chitkara (2008) utilized a fairly simple but powerful design by prompting students to form and work in groups using problem-based learning (PBL) in analog electronics. In addition to interacting as a group, students were provided with access to the Internet, library books, and facilities for experimentation. Presentation and teamwork skills were significantly improved compared with the control, as was attitude. The key aspect to this designed interaction was that it focused learners on complex problems as applied to the content domain. No special "tools" were necessary. While we frequently use costly simulations and games as examples of cognitive tools, designed interactions can achieve similar, positive outcomes using pedagogical strategies available to virtually all instructors with more affordable educational technology.

Kim and Reeves (2007) have further argued that it is difficult to conduct valid and useful research on cognitive tools for at least two reasons. The effects of tool use, they argue, develop over time so that research that takes a "one-shot" perspective may be contributing to the impression of ineffectiveness or missing important outcomes that require time to develop. They also argue that for group-based research, the unit of analysis should be the group rather than the individual student. Returning to Mantri et al. (2008), they addressed both of these issues, utilizing four 2-h group sessions over an entire course, group-based problem submissions, and peer evaluation. A more recent example is a study by Baepler, Walker, and Driessen (2014) that explored the effectiveness of a flipped classroom involving two groups over an entire term. During the in-class sessions, students "had access to optional online lectures, solved problems in small groups during class, worked with computer simulations, played a chemistry version of the game Jeopardy, and answered clicker questions" (p. 230). Kim and Reeves's reasoning might be extended to all research on collaborative learning, whether involving technology or not. While these suggestions possess a good deal of face validity, they present challenges to researchers working in real classrooms with real measures of achievement, which are usually based on individual performance. The above examples demonstrate, however, that these challenges can be overcome. One point is well taken: we need more research on cognitive tool use in collaborative learning environments, so as far as we are concerned, this meta-analysis represents a starting point rather than an endpoint for this kind of research.

5. Conclusion

This meta-analysis has examined how student achievement is influenced by incorporating interactions, especially designed interactions, into post-secondary learning environments. Increased engagement prompted by cognitive tools and communication result in superior outcomes. In 1995 Jonassen argued that "Cognitive tools are examples of learning with technologies rather than from them" (p. 40). This is a dramatic shift from Richard E. Clark's (1983) analogy that media is no more important to learning than is bread influenced by the truck that delivers it to market. That was the "learning *from*" perspective that dominated and probably inhibited the development of alternatives to presentation media that represent the "learning *with*" perspective. Educational technology is well past Clark, but we are not beyond remembering that technology is only as good as the learners it serves, the intended outcomes of instruction, and the instructional design that is used. Technology is just a tool and it behooves us to learn to employ it effectively.

Appendix

Summary Table of Technology, Pedagogy, and Indications of *Designed Interaction Treatments* ($k = 25$)

Study ID	Effect size defining distinction between the treatment and control condition on use of technology (Schmid et al., 2014)	Indications of *Designed Interaction Treatments* conditions	*ES* and sample size (n_E and n_c)
Al-Jarf (2005)	Traditional language instruction was supplemented in the experimental condition by an online (Web-based with Blackboard Corporation) component, but was limited to technology-free in-class instruction only, in the control condition.	*Specifically designed Discussion Board allowed sending and managing multiple communication threads and maintaining meaningful structured discussions over their postings of additional learning materials of their individual preference.*	$g = 1.23$ $n_E = 62$; $n_C = 51$
Arts, Gijselaers, and Segers (2002)	Experimental group PBL work in ALE (Authentic Learning Environment) was supported by various electronic tools, including CD-ROMs, authentic multimedia materials and means of CMC for small group discussions. PBL activities of the control group were carried out in fixed-place fixed-time F2F meeting with limited exposure to educational technology (predominantly Internet-based study resources).	*Maastricht business school student in teams of four were "self-steering" and adapted collaborative "business-like" group work practices using data from real companies. Small group activities included brainstorming and discussion sessions aiming at creating schematics for business case analyses. Each team problem solution was made known to other teams for feedback and eventual conversion of the problem solving and learning experience and effectiveness.*	$g = 0.56$ $n_{E.} = 31$; $n_C = 32$
Atan, Sulaiman, and Idrus (2005)	Experimental and control groups worked online (in PBL and CBL – content-based learning, respectively) environments on designated course Web-pages.	*PBL Web-based learning environment enabled several components of collaboration: discussion among peers to identify learning issues and propose hypotheses (solutions) and distribution (delegation) of responsibilities for finding relevant information.*	$g = 0.36$ $n_{E.} = 45$; $n_C = 22$
Cavaleiro, Guimaraes, and Calheiros (2009)	Undergraduate medical students in the experimental condition worked on the Zoe™ neonatal body simulator with computer-controlled mechanic apparatus. There was no technology exposure in the control group.	*Students worked with the simulator in groups of three, assumed roles of two neonatologists responsible for the patient's breathing and circulation and drag administration, respectively and of a nurse taking care of the support of newborn.*	$g = -0.80$ $n_{E.} = 24$; $n_C = 21$
Cho and Schunn (2007)	Both groups used SWoRD (scaffolded writing and reviewing in the discipline) Web-based reciprocal peer review system.	*Multi-Peer feedback condition supported students' authentic writing practice by providing multiple individual peer reviews, back-reviews (and grading) and an opportunity for scaffoled rewriting.*	$g = 0.45$ $n_{E.} = 9$; $n_C = 9$
Chou and Min (2009)	Students in the experimental condition used HomeMeeting JoinNet Version 4.1.0 software for communicating via audio, video, and data transmission facilities. There was no technology exposure in the control instructional condition.	*The instructional environment included the following elements of CSCL (Computer-Supported Collaborative Learning): shared access to a workspace and external learning resources, parallel inputs, group display, feedback and its interpretation, cooperative discussions, and joint recommendations.*	$g = 0.41$ $n_{E.} = 63$; $n_C = 63$
Dori and Belcher (2005)	Technology-Enabled Active Learning (TEAL/Studio) was the primary delivery method for the experimental group. The control condition was technology-free.	*TEAL students activities included working in various size (3–9) heterogeneous groups constructing knowledge by participating in peer discussions (asking*	$g = 0.36$ $n_{E.} = 690$; $n_C = 121$

Appendix (*continued*)

Study ID	Effect size defining distinction between the treatment and control condition on use of technology (Schmid et al., 2014)	Indications of *Designed Interaction Treatments* conditions	*ES* and sample size (n_E and n_c)
		questions, explaining ideas) and collaboratively carrying out hand-on desktop experiments.	
Glickman (2000)	R-CAI (Reform-Computer Assisted Instruction) experimental condition used the Prentice Hall's Interactive Mathematics software package – a course management system designed to deliver individualized self-paced symbolic manipulation instruction There was no technology exposure in the control group.	*Real World activities, designed to advance development of mathematics skills through real-world applications, required students to justify their solutions through structured group discussions, writing assignments, and individual and group projects.*	$g = 1.00$ $n_{E.} = 33$; $n_C = 34$
Halmhuber (1995)	Instruction in the experimental condition delivered via interactive computer-based multimedia module. There was no technology exposure in the control instructional condition.	*Students worked in cooperative learning groups to solve authentic (specific learning situations typical for general education classes) problems.*	$g = 0.48$ $n_{E.} = 24$; $n_C = 124$
Hwang, Wang, & Sharples (2005)	Web-based (HTML) learning materials in the experimental group were designed to enable students' personalized multimedia annotations to them via specialized VPen (Virtual Pen) system with the option for sharing information, while the control group utilized HTML-based learning materials without access to VPen system, only suitable for individual work.	*Within and across group annotation sharing processes were guided by collaboration learning scenarios and involved exchange of comments/ additions so that activity and diligence of participating in creating group annotations contributed to student individual success.*	$g = 0.83$ $n_{E.} = 33$; $n_C = 26$
Jehng (1997)	Experimental group worked in a distributed learning environment TurtleGraph – Mac-based (Apple Talk) networking software. There was limited technology exposure (a single computer per pair) in the control group.	*Knowledge building in computer-based distributed learning environment involved three key collaborative situations: communication, negotiation, and consolidation.*	$g = 0\ 0.12$ $n_{E.} = 36$; $n_C = 36$
Kennedy (2007)	Experimental group combined F2F lecture presentation with on-line (to enable access to extra resources for research) problem-based learning cases. There was no technology exposure in the control group.	*On-line PBL was carried out in small groups that worked on learning cases collaboratively facilitated by a trained tutor.*	$g = 1.49$ $n_{E.} = 14$; $n_C = 16$
Lane and Aleksic (2002)	Students in the experimental group participated in computer-enhanced lab sessions and had access to a course website that contained administrative and assignment information and links to various learning resources. No technology was employed in a lecture-based instruction for the control group.	*In the computer studio lab students were involved into collaborative group work: applying statistical concepts to real-world problems. Final grades were composed of a weighted individual and group assessment scores.*	$g = 0.47$ $n_{E.} = 532$; $n_C = 340$
Lee (2007)	Students in the experimental group used asynchronous CMC (online discussion board). There was no technology exposure in the control instructional condition.	*According to the authors, all stages of analyzing self-regulation instructional case studies (from problem identification to presentation of recommendations with the corresponding rationales) were carried out collaboratively.*	$g = -0\ 0.09$ $n_{E.} = 36$; $n_C = 47$
Lipman, Sade, Glotzbach, Lancaster, and Marshall (2001)	Experimental instructional condition supplemented traditional classroom instruction with Internet-based (WebCT applications) components. There was no technology exposure in the control instructional condition.	*Internet-based small group discussions of case studies were structured hierarchically and stratified by topic and by thread.*	$g = 0\ 0.34$ $n_{E.} = 64$; $n_C = 66$
Mantri et al. (2008)	PBL instruction in experimental condition was supported by Internet access. Control condition was technology-free.	*PBL work was team- based and included task rotation among team members coordinated by elected team leaders – different for different tasks, discussions of issues and joint work on setting goals and review of mistakes.*	$g = 1.18$ $n_{E.} = 21$; $n_C = 107$
Miller, Georger, and Pyzdrowski (1999)	Computer-supported algebra lab sessions in the experimental condition were contrasted to technology-free traditional method of instruction.	*Students worked cooperatively in small groups and pairs (with a selected partner) on lab assignments, shared lab grades, and weekly communicated via structured journal entries.*	$g = -0.14$ $n_{E.} = 9$; $n_C = 23$
Neumann and Hood (2009)	Students in the experimental condition worked in a Wiki (Web browser based hypertext system) learning environment. There was minimal technology (SPSS) exposure in the control condition.	*Students analyzed statistical datasets and communicated the results by jointly writing a practice report using a Wiki blended collaborative learning environment.*	$g = 0.49$ $n_{E.} = 27$; $n_C = 25$
Pedró (2005)	Experimental condition students worked in computer-supported environment (Campus	*Small group (up to 6) collaborative activities included solving four cases per*	$g = 0.04$ $n_{E.} = 46$; $n_C = 46$

(*continued on next page*)

Appendix (*continued*)

Study ID	Effect size defining distinction between the treatment and control condition on use of technology (Schmid et al., 2014)	Indications of *Designed Interaction Treatments* conditions	*ES* and sample size (n_E and n_c)
	Global e-learning platform). There was no technology exposure in the control condition.	*lecture unit followed by team presentations, class discussions, and peer and instructor feedback. Student performance was evaluated according to cooperative principles of positive interdependence and individual responsibility.*	
Schellens, Van Keer, De Wever, and Valcke (2009)	Students in both conditions participated in online asynchronous discussions.	*The study featured a computer-supported collaboration script ("Thinking Hats" CSCL environment) – a selection of message (thinking) types for students to categorize (select from) their posting before contributing messages to an online discussion forum.*	$g = 1.85$ $n_{E.} = 23$; $n_C = 12$
Shana (2009)	Two groups were involved in a course about distance education. The treatment condition used a textbook and course materials designed for the course, supplemented by weekly Web-based discussion forums. The control group received the same instruction but no discussion forums.	*The weekly Web-based discussion forums were specially designed for the treatment group based on John Keller's ARCS Model. Weekly discussion topic incorporated Keller's four steps to supporting student motivation: attention, relevance, confidence and satisfaction.*	$g = 1.13$ $n_{E.} = 15$; $n_C = 15$
Su (2008)	Experimental group students participated in computer puzzle, strategy and programming games. Technology use in the control condition was limited to small practical applications of Visual Basic as assignments.	*Students in small groups of three or four were engaged in collaborative discussions and played the "Jeopardy" game in competition with other group members.*	$g = 0$ 0.48 $n_{E.} = 64$; $n_C = 79$
Thompson and McCann (2006)	Replacement Model in the experimental condition was based on shifting large portion learning activities to the computer-based online format, while the control condition used technology-free fully face-to-face lecture-based instruction.	*Students participated in interactive learning activities including hands-on real world applications-based collaborative projects.*	$g = 0.42$ $n_{E.} = 170$; $n_C = 214$
Uribe, Klein, and Sullivan (2003)	Both groups studied in a computer-mediated Web-based learning environment (interface enabled through the Blackboard™ course management system). Instructional program was developed using Authorware™ and featured an animated agent that led students (presented textual explanations) through particular steps of problem solving process.	*Students in computer-mediated collaborative Web-based environment worked in pairs composed of learners with different ability levels. They communicated using virtual classroom feature of the Blackboard system to collaboratively solve assigned to them problems.*	"High ability" subgroup: $g = 0.46$ $n_{E.} = 16$; $n_C = 13$ "Low ability" subgroup: $g = 0.84$ $n_{E.} = 16$; $n_C = 14$

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