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Review

Let's talk evidence – The case for combining inquiry-based and direct instruction

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A R T I C L E I N F O

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A B S T R A C T

Many studies investigating inquiry learning in science domains have appeared over the years. Throughout this period, inquiry learning has been regularly criticized by scholars who favor direct instruction over inquiry learning. In this vein, Zhang, Kirschner, Cobern, and Sweller (2022) recently asserted that direct instruction is overall superior to inquiry-based instruction and reproached policy makers for ignoring this fact. In the current article we reply to this assertion and the premises on which it is based. We review the evidence and argue that a more complete and correct interpretation of the literature demonstrates that inquiry-based instruction produces better overall results for acquiring conceptual knowledge than does direct instruction. We show that this conclusion holds for controlled, correlational, and program-based studies. We subsequently argue that inquiry-based and direct instruction each have their specific virtues and disadvantages and that the effectiveness of each approach depends on moderating factors such as the learning goal, the domain involved, and students' prior knowledge and other student characteristics. Furthermore, inquiry-based instruction is most effective when supplemented with guidance that can be personalized based on these moderating factors and can even involve providing direct instruction. Therefore, we posit that a combination of inquiry and direct instruction may often be the best approach to support student learning. We conclude that policy makers rightfully advocate inquiry-based instruction, particularly when students' investigations are supplemented with direct instruction at appropriate junctures.

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The question of how to best teach science (or more generally STEM) topics has resulted in a long-standing and sometimes quite fierce debate. This debate centers on whether inquiry-based instruction is a more productive form of instruction than direct instruction. Over the years, a number of publications have asserted that for teaching approaches to be effective, they should have direct instruction, rather than inquiry, as their core (e.g., De Bruyckere, Kirschner, & Hulshof, 2015; Hodson, 1996; Kirschner, 2009; Kirschner, Sweller, & Clark, 2006; Sweller, 2009). More practice-oriented publications (e.g., Clark, Kirschner, & Sweller, 2012) and posts on social media have echoed this point of view. These arguments have resurfaced in a recent publication by Zhang et al. (2022), which stated that policy reports that recommend using an inquiry or “scientific practice” approach for instruction have based their recommendations on the wrong evidence and have moreover ignored vital evidence. They further argued that these policy documents would have recommended direct, explicit instruction if they had followed the pertinent empirical research. The aim of the current article is to provide an overview of existing literature related to the inquiry-based versus direct instruction debate in science education to show that Zhang et al. (2022) presented incomplete and, at some points, incorrect evidence. Moving beyond this polemical debate, we critically examine the conditions under which inquiry-based methods and direct instruction can enhance student learning. Based on this analysis, we make recommendations for future research, instructional design, and classroom practice, concluding that combinations of both approaches are probably the most effective.

1. The many faces of inquiry-based and direct instruction

When making a comparison between instructional approaches, it is necessary to start with a clear understanding of what each approach entails. Difficulties immediately arise at this point, because researchers have advanced many definitions and derivative approaches for both inquiry-based and direct instruction. The complexity is further exacerbated for inquiry-based instruction, because inquiry can serve different learning goals (Hmelo-Silver, Duncan, & Chinn, 2007; Rönnebeck, Bernholt, & Ropohl, 2016). Inquiry itself can be seen as the goal of learning in an instructional context, so that students learn what inquiry is, how to perform its various tasks and engage in disciplinary practices and procedures, and what the nature of science is. Alternatively, inquiry can be a means to learn about specific scientific concepts and phenomena (Abd-El-Khalick et al., 2004). In this paper, we focus on the second use of inquiry, namely, as a way to construct (conceptual) knowledge about science topics, because this is also the main goal of direct instruction. Additional potential learning outcomes of inquiry learning are discussed where appropriate.

In a recent handbook on inquiry learning, Chinn and Duncan (2021) identified six components that characterize inquiry learning. The first is that students generate knowledge that is new to them by carrying out an investigation. In this context, Trout, Lee, Moog, and Rickey (2008) contrasted what they called traditional instruction with inquiry-based instruction. They emphasized that in traditional instruction, explanation precedes experimentation, while experimentation is performed in a ‘cookbook’ manner solely to confirm what the teacher or textbook have already explained. In that case, students do not seek to learn something new themselves. Second, in inquiry settings students must work actively to get to these new findings. This means that they do not just rely on what they are being told; rather, they perform activities that generate knowledge. The inferences they need to construct new knowledge should also not be trivial. Third, students must use evidence to come to their conclusions. This evidence can come from many different sources. In science classes, evidence is most frequently generated by experiments that students perform, but it can also appear in informational documents such as news articles, scientific reports, or adapted reports of scientific studies. Fourth, student should have “epistemic agency” (Stroupe, 2014), which means that students have responsibility for their own learning process and can share their thoughts with a community of learners. This can also mean that students come up with their own questions that they would like to answer. Fifth, there is always some complexity in the reasoning involved. In inquiry, students must consider multiple sources of evidence and always think about alternative explanations for their findings. Sixth, full-fledged inquiry always involves a community. This means that students share their approaches and conclusions with other students and can face critical questions from each other. In summary, central to inquiry is that students generate knowledge actively themselves, that they use evidence to come to conclusions, that this evidence is often generated by performing investigations, and that approaches and conclusions are shared with others and critically evaluated. These inquiry learning activities, if well designed and supported, can position students to resolve cognitive conflicts (Limón, 2001; Potvin, 2023) and can induce deep learning processes such as elaboration, self-explanation, and metacognitive strategies (Eysink & de Jong, 2012). In educational practice, inquiry-based science classes may incorporate the six components mentioned above to varying degrees, thus enabling teachers to adapt the inquiry saturation of their lessons to situational demands.

Several policy documents (National Research Council, 1996; National Science Foundation, 2000) have discussed inquiry processes that clearly have a link to the six components identified by Chinn and Duncan (2021). Examples are “making discoveries” (finding out), “planning and conducting investigations,” “gathering data,” “interpreting data” (using evidence), “thinking critically,” and more specifically, “asking questions” and “constructing and analyzing alternative explanations” (epistemic agency). In newer policy documents (National Research Council, 2012, 2013), the term "inquiry" has been replaced by "scientific practices" to reflect the interconnected nature of science and the role of shared norms that undergird scientific activity. Underlying these practices are the components mentioned above, along with two new competencies: "developing and using models" and "using mathematics and computational thinking."

Despite what is sometimes proclaimed by opponents of this approach, inquiry-based instruction designed for classroom use is typically well-structured, carefully designed and sequenced, as in the Physics by Inquiry curriculum (McDermott & the Physics Education Group, 1996), Process-Oriented Guided Inquiry Learning (POGIL) (Joshi & Lau, 2023; Moog & Spencer, 2008; Walker & Warfa, 2017), nQuire (Sharples et al., 2014), and the Web-based Inquiry Science Environment approach (Slotta & Linn, 2009). Inquiry learning often follows an inquiry cycle with a distinct number of phases (Pedaste et al., 2015). In each of these phases, the central activity can be initiated by the teacher or by the student, thus creating a continuum ranging from fully open student-initiated inquiry to fully teacher-led—the latter, of course, missing an essential characteristic of inquiry (see, e.g., Bell, Smetana, & Binns, 2005; Bonnstetter, 1998). In addition, inquiry-based instruction (the term we use for guided inquiry learning) includes various types of guidance, as is extensively discussed in the available literature (see e.g., de Jong & Lazonder, 2014; Sun, Yan, & Wu, 2022; Zacharia et al., 2015).

In defining direct instruction, Zhang et al. (2022, p. 1160) gave examples such as "simply providing students with the desired information and having students read it from texts or watch demonstrations" and stated that direct or explicit instruction can include "simply giving students answers, having students watch demonstrations and listen to explanations, directly reading answers from texts, etc." (Zhang et al., 2022, p. 1165). A more elaborate description was given by Stockard, Wood, Coughlin, and Khoury (2018), who, based on the work by Engelmann (1980), stated that teachers or textbooks are in the lead in direct instruction, mastery learning is critical, in that the next steps can only be taken when a preceding skill has been mastered, and complex skills are subdivided into smaller skills that are trained separately. The 4C/ID (Four Component Instructional Design) model (van Merriënboer & Kirschner, 2018) is an example of a well-known, successful approach rooted in these principles. Direct instruction also advocates training smaller skills together in a realistic context. Although some work has drawn subtle distinctions between direct and explicit instruction (e.g., Hughes, Morris, Therrien, & Benson, 2017), we follow Zhang et al. (2022) and use the two synonymously, always following the terminology of the authors we cite—which requires us to occasionally use the term "traditional instruction" instead.

In the overview of studies in the next section, direct instruction is mostly defined as instruction that, at its core, conveys information directly—for example, by lecturing and by giving a leading role to the teacher or system (e.g., textbook). It is important to note, however, that there are also definitions of direct instruction that do not regard this approach as synonymous with fully passive learning. Direct instruction admittedly contains a passive component (lecturing, text presentation in books), but students can also be active in making sense of the information offered, for instance, through notetaking or practicing the knowledge and skills taught by solving associated problems (Chi, 2009; Hughes et al., 2017). One need only watch videos of Siegfried Engelmann (one of the scholars who coined the term direct instruction) implementing his version of direct instruction to notice that there is much more active engagement than simply providing information (Engelmann, 1980). Although, as indicated above, students in direct instruction can use experimentation to confirm already learned theories, students are not asked to invent, construct, or discover any of the critical practices, concepts, or principles on their own. These nuances in inquiry-based and direct instruction play a key role in interpreting the evidence for the relative effectiveness of both instructional approaches in the next section.

2. What does the evidence say?

In this section we review evidence from the literature that bears on the relative effectiveness of inquiry-based and direct instruction in the three research areas that Zhang et al. (2022) distinguished: controlled studies, correlational work, and program-based studies. Although definitions of both instructional approaches may vary over different studies, their core features are consistent.

2.1. Controlled studies

Zhang et al. (2022) stated that results from controlled studies are largely ignored in policy documents advocating inquiry-based instruction. They argued, "Overwhelmingly, these studies supported the suggestion that students demonstrated greater learning of the content from the various forms of direct instruction …" (p. 1160). However, they substantiated this claim in their paper mainly by citing a limited number of primary studies from a selected set of authors, thereby bypassing a massive number of controlled studies that have shown the benefits of inquiry-based instruction in comparison with direct instruction. Instead of citing selected individual studies here, we have chosen to rely on meta-analyses and systematic review studies that have summarized this work, covering relatively recent as well as older primary studies. These studies have the advantage that the authors systematically collected all relevant evidence bearing on the issue.

We were able to find one meta-analysis (Stockard et al., 2018) that found benefits for direct instruction, covering 328 studies not from STEM specifically but from the areas of reading, math, language, and spelling. Stockard et al. (2018), however, did not classify the type of instruction used in the comparison group; they merely distinguished between "… the curriculum usually or already used at a school or some type of experimental curriculum …" (p. 488). This lack of detail prevents drawing valid conclusions about which forms of instruction were inferior to direct instruction in their analysis. The outcomes of other research syntheses have consistently shown that instructional approaches that include inquiry learning are more effective than direct instruction (with both constructs labeled in a variety of ways). Minner, Levy, and Century (2010) analyzed the findings of 138 studies that included some level of inquiry and found that 51% of the studies indicated a positive effect of inquiry-based instruction on the acquisition of conceptual knowledge. Only 2% of the studies showed a negative impact, while the remaining studies showed mixed results or found no difference. The primary studies in the analysis by Minner et al. (2010) adopted various research designs, and the majority of them would be characterized by Zhang et al. (2022) as program-based studies (which are discussed later). Nonetheless, 42 studies in the Minner et al. (2010) dataset involved a direct and controlled comparison (i.e., using experimental or quasi-experimental designs) of instructional treatments with varying degrees of inquiry saturation, which was defined as the level of active thinking, responsibility for learning, and motivation. More than half of these studies (55%) showed a significant positive effect of treatments with a higher level of inquiry over approaches with lower levels of inquiry, and only one study (2%) showed an advantage for lower inquiry saturation.

In a meta-analysis comparing inquiry-based instruction and direct instruction on the basis of 164 primary studies, Alfieri, Brooks, Aldrich, and Tenenbaum (2011) concluded that unassisted (or unguided) discovery is less effective than explicit instruction, but that assisted inquiry is more effective than explicit instruction involving "explicit teaching of strategies, procedures, concepts, or rules in the form of formal lectures, models, demonstrations, and so forth and/or structured problem solving" (p. 5). Furtak, Seidel, Iverson, and Briggs (2012) analyzed 37 (quasi-)experimental studies comparing inquiry-based instruction with direct instruction (labeled as textbook approach, traditional instruction, individual mastery learning, etc.) and reported an overall positive effect of inquiry-based instruction, with an additional positive effect of approaches in which there was teacher guidance. These two meta-analyses suggested that guidance is needed to make inquiry learning effective. In a meta-analysis that included 72 studies using randomized or quasi-experimental designs, Lazonder and Harmsen (2016) similarly showed that guidance increases the positive effect of inquiry-based approaches on learning outcomes by half a standard deviation. Similar results on the added value of scaffolding for a series of problem-centered instructional approaches in science, including problem- and project-based learning and inquiry, were reported by Belland, Walker, Kim, and Lefler (2017) in a meta-analysis including 144 studies.

The above-mentioned research syntheses included both digital and non-digital instructional approaches in the studies that they surveyed; other studies focusing specifically on digital approaches have come to similar conclusions. Smetana and Bell (2012) analyzed the results of 61 empirical studies focused on comparisons of inquiry-based instruction with computer simulations and other forms of instruction, including lecture-based, textbook-based, and hands-on instruction. As these authors wrote, "Used appropriately, computer simulations involve students in inquiry-based, authentic science explorations" (Smetana & Bell, 2012, p. 1337). They found that the great majority of the studies (49; 80%) indicated an advantage for the simulation-based group, but also concluded that to be effective, simulations need high-quality support structures. In line with this conclusion, noted that the use of computer simulations is often recommended as a supplement to real laboratory work (see also, Wörner, Kuhn, & Scheiter, 2022) or direct instruction (see later). In their work, Smetana and Bell (2012) did not report whether all included studies were well-controlled.

Another conceptual review comparing simulation-based (inquiry) learning with traditional instruction (both traditional classroom instruction and hands-on lab instruction) was published that same year (Rutten, van Joolingen, & van der Veen, 2012). This review analyzed 48 (quasi-)experimental studies in which simulations associated with inquiry-based instruction were used as an enhancement or replacement for traditional forms of instruction. The authors' conclusion echoed that of Smetana and Bell (2012): active learning with simulations improves students' learning outcomes, but support is needed. A meta-analysis of 59 articles (d'Angelo et al., 2014) that included either an experimental or quasi-experimental design and compared simulation-based learning with support, simulation-based learning without support, and non-simulation-based instruction reported 128 effect sizes: 96 for content knowledge, 17 for scientific inquiry and reasoning skills, and 15 for noncognitive outcomes. These authors' overall conclusion was that simulation-based instruction had an advantage over non-simulation-based instruction on all three outcomes, and that simulations that included additional support had a (modest) advantage over those lacking that support. The type of research design (randomized controlled trial or quasi-experiment) did not influence the magnitude of the effect sizes.

The reviews and meta-analyses discussed above always included primary studies that had conceptual knowledge as their outcome, sometimes along with other outcome measures. Another focal outcome is students' development of inquiry skills, including the control-of-variables strategy (CVS; Chen & Klahr, 1999). For example, Klahr, Zimmerman, and Jirout (2011) found that "direct instruction" was better than exploration for the development of CVS. In that work, however, the instruction went beyond the definition of direct instruction offered by Zhang et al. (2022) who described direct instruction as "simply providing students with the desired information and having students read it from texts or watch demonstrations" (p. 1160). Klahr et al. (2011), in contrast, asked students to engage in active inquiry, designing and evaluating experiments, and gave feedback on students' active inquiry attempts. Other work has shown that acquiring CVS can be accomplished well in the context of experimentation (e.g., Schalk, Edelsbrunner, Deiglmayr, Schumacher, & Stern, 2019), especially with regard to long-term effects (Dean & Kuhn, 2007). These primary studies give an idea of the diversity of results. A meta-analysis on the effect of instruction on acquiring CVS was presented by Schwichow, Croker, Zimmerman, Höffler, and Härtig (2016). About this study Zhang et al. (2022, p. 1165) wrote: "A comprehensive analysis of 72 intervention studies examining students' learning how to control variables during investigations (Schwichow et al., 2016) concluded that there is no evidence supporting the claim that teaching through inquiry-based, exploration-type investigations leads to better learning." However, Schwichow et al. (2016) found no relative advantage for direct instruction (defined as "explicit rule teaching", p. 57) either. In this respect, Schwichow et al. (2016) stated:

> In contrast with findings from single intervention studies (e.g., Chen & Klahr, 1999; Klahr & Nigam, 2004) we found studies that explicitly taught a CVS rule to have effect sizes ($g = 0.58$, 95% CI = 0.46–0.70) no different from studies in which CVS rules were not explicitly taught ($g = 0.65$, 95% CI = 0.51–0.79). (p. 54)

The great majority of the cited meta-analyses and systematic reviews (and almost all of their underlying primary studies) were not mentioned in the Zhang et al. (2022) paper. Although the Lazonder and Harmsen (2016) paper was included, this study was misquoted. Zhang et al. (2022, p. 1165) wrote that these authors "concluded that students' learning gain did not result from completing learning tasks by acting as scientists, but derived from direct explanations added to the program," which is an incomplete and incorrect summary of this study's main finding. Instead, Lazonder and Harmsen (2016, p. 702) concluded from their analyses that "The type of guidance had no significant moderation effect, meaning that all six types of guidance, regardless of their specificity, were equally effective in promoting learning outcomes." Only one of the six types of guidance was direct instruction, so it is misleading to claim that the learning gains resulted solely from direct explanations.

As has become clear from the overview above, a key issue in interpreting the impact of inquiry-based instruction is the role of guidance. The idea that "pure discovery" could be a fruitful approach is not supported in the literature (Mayer, 2004). Benefits for inquiry from both online and teacher guidance have been extensively reported elsewhere (e.g., Furtak et al., 2012; Gerard et al., 2016; Lazonder & Harmsen, 2016; Quintana et al., 2004; Zacharia et al., 2015). This guidance can include direct instruction to facilitate inquiry activities (see also de Jong & Lazonder, 2014). Thus, favorable results of guided inquiry can in some cases be (partly) due to guidance that includes direct instruction (see also, Zhang & Cobern, 2021). Other forms of guidance such as Socratic dialogue (McDermott & the Physics Education Group, 1996) and online scaffolds (Zacharia et al., 2015) have also been shown to benefit learners.

2.2. *Correlational studies*

A second source of evidence concerning the effect of inquiry-based instruction comes from correlational research, such as studies using data from PISA. Here we focus on data from the PISA 2015 assessment (OECD, 2016). In addition to measuring students' science achievement, this assessment contained questions on the occurrence of inquiry-related activities in the classroom. One concern with the PISA 2015 data is that the information collected on inquiry practices was based on self-reports: Students had to answer questions that addressed the occurrence of these activities in their classes. As already indicated in much other work (e.g., Aditomo & Köhler, 2020), students' reporting can be inaccurate (e.g., it could include cookbook-based laboratory experiences), and the PISA 2015 data did not report on the quality of the inquiry lessons offered.

Nonetheless, one of the main and often-cited messages from PISA 2015 is that initial analyses of these data found an overall negative relation between the frequency of inquiry learning activities and students' science performance (Cairns & Areepattamannil, 2019; Jerrim, Oliver, & Sims, 2019; Oliver, McConney, & Woods-McConney, 2021). Zhang et al. (2022) emphasized this point. However, setting aside the concerns about how inquiry is operationalized, a more nuanced picture emerges upon zooming in on the data (see also de Jong, 2021). First, the relation between the frequency of inquiry learning activities and science achievement scores is not linear but curvilinear, meaning that inquiry activities do have a positive relation with science performance up to a certain level (Chen, Dorn, Krawitz, Lim, & Mourshed, 2017; Oliver et al., 2021). Such a curvilinear relation seems to be a firm phenomenon, because it was also found in TIMSS data (Teig, Scherer, & Nilsen, 2018) and confirmed in a meta-analysis covering PISA and TIMMS data (Teig, 2022). This finding might indicate that different approaches need to be combined in a curriculum for optimal learning, which could point to the need to consider appropriate combinations and sequencing of direct instruction and inquiry learning. This was also the conclusion by Chen et al. (2017), who found on the basis of PISA 2015 data that the highest average score increase was associated with inquiry learning in combination with forms of direct, teacher-based instruction. These authors called this the "sweet spot" of instruction (Chen et al., 2017, p. 42), meaning that students need a certain level of content mastery to optimally profit from inquiry-based learning. Such a conclusion also aligns with the results of a synthesis study by Hattie and Donoghue (2016), who found that acquiring deep knowledge can be enhanced when instruction in which students are explicitly taught the necessary prior knowledge precedes active learning methods, including inquiry-based instruction and problem-based approaches (see also Frey, Fisher, & Hattie, 2017). In a similar vein, Areepattamannil, Cairns, and Dickson (2020) concluded from an analysis of the PISA 2015 data that a blending of teacher-directed instruction and inquiry activities was also favorable for developing students' positive dispositions toward science.

Second, more detailed analyses of PISA 2015 data have also investigated the role of teacher guidance. Aditomo and Klieme (2020) analyzed the data from the 10 highest and 10 lowest performing regions in PISA 2015 (>150,000 students from >5000 schools), examining *independent inquiry*, in which students performed their inquiry activities without support by the teacher, and *guided inquiry*, in which teacher guidance was present. The results showed that guided inquiry was positively associated with science achievement in all 16 regions where this form of instruction was applied. Jerrim et al. (2019) also found indications based on PISA 2015 data from England that guidance combined with inquiry was positively correlated with science achievement. Wang et al. (2022) drew a similar conclusion based on the PISA 2015 data from Australia and Taiwan.

A third nuance is that inquiry is a multifaceted activity. Oliver et al. (2021) investigated the scores on individual items of the PISA 2015 inquiry scale for six Anglophone countries. They found that some instructional activities that they considered as inquiry-related were negatively associated with science achievement (e.g., holding class debates), whereas other aspects had a positive relation (frequency of doing practical experiments and of drawing conclusions from these experiments). A similar conclusion was drawn by Cairns (2019) on the basis of PISA 2015 data from 69 countries. Cairns (2019) found that some inquiry activities had a positive relation with science achievement whereas others showed a negative relation; still others (most particularly, explaining ideas and doing experiments) had a curvilinear relation with achievement. This analysis also confirmed that open inquiry without teacher guidance is negatively associated with science achievement.

Thus, the results of correlational studies substantiate the conclusions from controlled studies: Successful instructional approaches can include student investigations as long as adequate guidance, possibly including direct instruction, is given for designated aspects of the inquiry process.

2.3. Program-based studies

A third source of evidence comes from program-based studies. Although Zhang et al. (2022) provided a rather loose definition of this type of research, program-based studies in their work seems to refer to studies that cover an entire program or a curriculum. These studies normally concern a longer and more encompassing intervention than the well-controlled, short-term studies that are typically conducted in research laboratories or regular classrooms. Zhang et al. (2022) wrote that there is often no control group involved with program-based studies, and that when there is a control group, it may remain unclear what the role of inquiry was in the overarching program under investigation. Many of these programs, in addition, also involve teacher training and other interventions (e.g., the introduction of technologies) over and above the use of inquiry-based methods of instruction. In this context, when discussing the meta-analysis by Minner et al. (2010), Zhang et al. (2022, p. 1164) wrote:

> Their review indicated that many Instructional components were included simultaneously when examining the impact of inquiry interventions and the levels of inquiry components included in the interventions varied substantially. Accordingly, the vast majority of studies examining inquiry-based science instruction are unable to serve as evidence supporting inquiry as an instructional approach.

This is not a persuasive argument, however, because the same holds for classroom implementations of direct instruction, which often include additional elements such as problem-solving activities or support such as highlighting subgoal structures in worked examples, and the like. It is still interesting and significant to find that the approaches characterized as inquiry-oriented at their core turned out to be more effective than approaches that had direct instruction as their core. Thus combining elements seems unavoidable when designing realistic, comprehensive real-classroom intervention.

A second comment by Zhang et al. (2022) on program-based studies was that if control groups are used, these are often “business as usual” controls, which amounts to unfairly comparing a well-designed, more encompassing inquiry-based condition with a condition that is not carefully designed by the researchers. However, if the control condition is a “business as usual” one, it is possible that teachers are very experienced in this traditional approach and can capitalize on their expertise in delivering the more direct form of instruction; furthermore, students also know exactly how to act in this traditional form of instruction. Therefore, we still think these very large-scale studies further contribute to the evidence with respect to inquiry-oriented approaches to instruction.

One example of such an extensive program-based study was conducted by Linn, Lee, Tinker, Husic, and Chiu (2006). More than 8000 students were involved in this study, in which two cohorts were compared on their achievement in six courses in different science content areas. The first cohort followed the typical curriculum; the second followed a curriculum spanning 2–10 days that was based on inquiry learning, incorporating technologies (e.g., interactive visualizations) developed in the WISE platform (Slotta & Linn, 2009). Students in the inquiry-based curriculum showed higher science achievement overall than students in the typical curriculum; this difference was statistically significant in four of the six courses. The study by Linn et al. (2006) developed an extensive instructional design for the experimental group and used a “business as usual” control group, but there have also been several long-term program-based studies involving contrasting interventions that were both carefully and specifically designed for the study. One example is the randomized controlled study by Schuster, Cobern, Adams, Undreiu, and Pleasants (2018). These authors designed lessons on the physics topics of dynamics and light using direct instruction or inquiry learning. The lessons covered 8 days and were delivered during a 2-week summer course attended by more than 100 participants per year over a 5-year period. No significant differences between conditions were found, and the authors stated in their abstract, “Findings suggest that teachers need not be bound to one mode throughout and can flexibly decide on the pedagogical approach for each concept and situation, on several grounds other than efficacy of core content acquisition alone” (Schuster et al., 2018, p. 389). As another example, Lederman and Lederman (2009) reported a study in which three conditions were designed for topics from chemistry and physics: a direct instruction condition, an inquiry condition, and a mixed condition. Participating teachers were trained in each of the three approaches and implemented each approach in different classes. The study was conducted in actual classrooms in the US and Sweden. No differences in acquired subject-matter knowledge, knowledge of inquiry, or attitudes towards science were found across the three conditions.

This brief sample of what can be called program-based studies shows that these studies can be conducted in a relatively controlled way. The evidence from these studies certainly does not show overall superiority of the direct instruction approach.

3. Moderating factors

The research discussed above centered around whether guided inquiry or direct instruction is more effective when taken as the core of the instructional approach. In our view, however, the debate should move beyond this contrast, because the merits of either approach can be very context dependent. Even though the literature is replete with statements that one instructional approach is better to use than the other, we argue that these generalizations should be tempered, for both direct instruction and inquiry-based instruction alike, because of the many moderating factors that can determine the effectiveness of an approach (see e.g., Kaplan et al., 2020). It is therefore time to take the debate to the next level and explore who benefits more from which approach and for what content, and to use the results of this analysis to propose ways to successfully combine inquiry-based and direct instruction in a lesson or a curriculum. The next two sections explore these issues.

In a recent paper, Hirsh, Nilholm, Roman, Forsberg, and Sundberg (2022) analyzed the 75 most cited review studies on teaching methods from 1980 to 2017 and identified moderating factors that influence the outcomes of instructional approaches. They summarized four categories of factors: a) differences in students (e.g., achievement level, cognitive level, level of previous familiarity with method), b) differences in teachers (e.g., professional experience, subject-specific knowledge, knowledge of the method used), c) differences in context (size or composition of student group, physical classroom context), and d) differences in content (school subject and quality of the teaching program). As noted earlier, the effectiveness of inquiry-based and direct instruction can be moderated by the quality of the teacher or the support provided by a digital system. In addition, factors such as the instructional content, the learning goals, the students' characteristics, and their prior knowledge about the topic may play an important role in the effectiveness of an approach. We discuss the impact of these contextual factors below to illustrate possible directions for future research and propose evidence-informed design recommendations for implementing and integrating student inquiry and direct instruction.

3.1. *Instructional content and learning goals*

Not every topic worth learning lends itself well to inquiry learning (National Research Council, 2000). Factual information (e.g., the chemical formula of water is H_2O) and straightforward operations (e.g., how to calculate the number of atoms in 118 g of water) are probably best taught through direct instruction. But when the subject matter is ill-structured, open to multiple interpretations, or susceptible to misconceptions (e.g., how does water's boiling point change with altitude, Desilver, 2015), inquiry learning can foster deep conceptual understanding (e.g., de Jong, 2019) and transfer of learned material to different tasks and settings (e.g., Gobert, Sao Pedro, Li, & Lott, 2023; Li, Gobert, & Dickler, 2019).

Above and beyond subject-matter characteristics, teachers and curriculum designers should align their instructional and assessment methods with the kind of learning outcomes they expect from students. Early instructional design theories (see, for an overview, Reigeluth, 1983) readily acknowledged the importance of aligning learning strategies with learning outcomes. These theories recommended using the expository strategies inherent in direct instruction if the goal of the lesson is to remember a piece of conceptual knowledge or a particular procedure. Inquiry-based strategies, on the other hand, were seen as more appropriate for promoting deep understanding and transfer of the subject matter, which students who followed traditional instruction often lacked (see e.g., Ortiz, Heron, & Shaffer, 2005). Frey et al. (2017) showed that these recommendations still hold today. They theorized that different strategies are needed for developing surface, deep, and transferable knowledge, and observed that inquiry-based methods were used effectively in lessons beyond the surface learning phase (see also Hattie & Donoghue, 2016). So, our first design recommendation is to employ inquiry-based methods if the instructional goal requires students to develop deep and transferrable conceptual understanding of topics that are open-ended or susceptible to misconceptions. Direct instruction is generally more appropriate and probably more efficient for acquiring well-structured and foundational (surface) knowledge, and it will not necessarily lead to deep conceptual understanding in less-well-structured domains (Frey et al., 2017).

3.2. *Prior knowledge*

Another insight that can be gleaned from early instructional design theories is that students' initial knowledge is an important condition for productive inquiry-based learning. Underlying some of these theories are learning hierarchies (e.g., Gagné, 1985) that specify the knowledge and skills students should possess before being exposed to more advanced instructional content and methods. Specifically, the foundational (prerequisite) knowledge associated with a topic should be taught before its more advanced aspects can be addressed and deep understanding is developed. Because inquiry-based instruction is most obviously effective for the latter type of learning, students likely benefit from some familiarity with the topic before generating hypotheses and finding a focus for inquiry (Al Mamun, Lawrie, & Wright, 2020; Lazonder et al., 2008, 2009). Ho, Tsai, Wang, and Tsai (2014) further showed that domain familiarity helps with interpreting data in tables and graphs. However, complete mastery of these prior knowledge and skills seems less imperative. In fact, students with lower prior knowledge tend to benefit more from the guidance they receive during an investigation than students with intermediate or high prior knowledge do (Gerard & Linn, 2022; van Riesen, Gijlers, Anjewierden, & de Jong, 2018). This differential influence of guidance could be one of the reasons why Kogan and Laursen (2014) found that low-achieving students who took an inquiry-based college math course earned higher grades in subsequent courses compared to low achievers who learned the same content through teacher-led instruction (i.e., large lectures with recitations). In contrast, the subsequent grades of average and high achievers did not differ as a function of instructional approach. In this context, it is also important to note that students should have a basic understanding of the inquiry process in order to be able to successfully carry out an investigation (Mäeots & Pedaste, 2014). Our second design recommendation therefore states that the potential benefits of inquiry-based learning only hold when students possess the necessary prior knowledge and have a basic command of inquiry skills. If one of these conditions is violated, direct instruction could be used to remediate deficiencies either prior to, during, or after the students' inquiry process.

4. Student characteristics beyond prior knowledge

Students within a classroom vary in many characteristics besides prior knowledge that can mediate their ability to benefit from specific instructional designs. For example, the effectiveness of inquiry-based and direct instruction depends on students' proficiency in reading, mathematics, or other areas (e.g., Koerber & Osterhaus, 2019; Slim, van Schaik, Dobber, Hotze, & Raijmakers, 2022). Research has consistently shown that reading comprehension predicts the level of inquiry skills in elementary schoolchildren; readers with good comprehension also possess more knowledge of inquiry skills than poor readers do (e.g., Mayer, Sodian, Koerber, & Schwippert, 2014; Schieffer, Golle, Tibus, & Oschatz, 2019; Schlatter, Molenaar, & Lazonder, 2020). Mathematical skills such as comparing, classifying, estimating, measuring, and calculating are also relevant to inquiry learning (Gallenstein, 2005; Kuntze, 2004), and proficiency in these skills indeed correlates with level of inquiry skills (e.g., Koerber & Osterhaus, 2019; Schlatter et al., 2020).

Studies of inquiry learning at the high school and university levels have explored how general cognitive factors mediate the productive application of inquiry skills and the amount of knowledge students develop from a self-conducted investigation. Veenman, Wilhelm, and Beishuizen (2004) found moderate positive correlations between adolescents' intellectual ability (measured by a battery of intelligence test scales) and the domain knowledge they acquired in an inquiry. Other studies have investigated the role of executive functions such as inhibitory control. Kwon and Lawson (2000) found that high school students' degree of inhibitory control predicted 29% of the variance in scores on an inquiry skills test and 28% of the variance in conceptual knowledge gains during a 14-lesson inquiry-based unit. Likewise, in a study of high school students learning from exploratory chemistry simulations, Homer and Plass (2014) found that students with a high degree of inhibitory control performed better on the transfer items of a domain knowledge test than their low inhibitory-control counterparts. These results are consistent with the expectation that inquiry learning prepares students to be self-directed learners. Those who already possess such skills are more likely to succeed.

Another student characteristic that seems important is self-efficacy—in other words, the student's level of confidence about succeeding in a specific domain or at a certain skill (Bandura, 1977). Ketelhut (2007) found that students' inquiry behavior correlated with initial self-efficacy in doing inquiry science, in the sense that students with high self-efficacy engaged in more data-gathering activities than students with low self-efficacy. However, this relation disappeared after students learned for a while in the (scaffolded) inquiry learning environment. Using PISA 2015 data, Liu and Wang (2022) found a moderating (direct) effect of guidance on the positive relation between science self-efficacy and inquiry learning. This finding suggests that the positive experience of inquiry-based instruction (guided inquiry learning) increases students' level of self-efficacy (see also, Husnaini & Chen, 2019; Sulistiyo & Wijaya, 2020; Thisgaard & Makransky, 2017). The relevance of self-efficacy when choosing direct instruction or an inquiry approach became clear in a recent study by Richter, Lachner, Jacob, Bilgenroth, and Scheiter (2022). They found that a direct instruction condition was more successful overall than inquiry learning conditions for university students acquiring conceptual knowledge about photosynthesis. However, a further analysis by these authors showed that this was only the case for students with a low domain self-concept, again highlighting the importance of attending to individual differences when considering the effectiveness of an instructional approach.

These cited studies lead to our third design recommendation: Differentiate instructional guidance within an inquiry-based classroom based on students' reading comprehension and math skills, intelligence, inhibitory control, and self-concept. Specifically, students with lower profiles in these areas should be given more explicit support, which might well include short episodes of direct instruction (de Jong & Lazonder, 2014; Lazonder, 2023; Therrien, Benson, Hughes, & Morris, 2017). Future research should extend this initial set of moderating student characteristics and the way they are best accommodated.

We conclude our discussion of moderating factors by arguing that our design recommendations, although still tentative, have two clear implications. First, in many cases, guidance can be used to respond to specific moderators, for example, by providing more structure for students with low inhibitory control. More research is needed to explore interactions between the moderators and specific forms of guidance. Second, learning environments often should include elements of both inquiry-based and direct instruction over time. Indeed, we would argue that most designers of inquiry learning environments already include elements of direct instruction at various junctures in their curricula; students are told some things and must discover others. The urgent question for research and practice, then, is how to combine inquiry and direct-instruction elements to best support learning. The continuing debate over *which* approach is better should, therefore, give way to discussions of *how* different elements of each approach are best integrated in various contexts.

5. Combining direct and inquiry-based instruction

The previous section sketched differential effects of inquiry-based and direct instruction depending on moderating factors. In practice, implementations of lessons, lesson series, and complete curricula have multiple dimensions. Regardless of whether direct instruction or inquiry is the core of a lesson, lesson series or curriculum, additional instructional strategies and activities are usually needed to make the approach work. Different instructional strategies can coexist in a lesson. Teachers can, for example, wrap up an inquiry-based lesson with a whole-class discussion to review students' research outcomes and present or clarify the underlying core concept (see e.g., Vilarta Rodriguez, van der Veen, Anjewierden, van den Berg, & de Jong, 2020). In situations like these, expository and investigative learning activities are designed to strengthen each other.

Thus, inquiry learning can promote a readiness to learn from direct instruction (Hmelo-Silver, Kapur, & Hamstra, 2018). Research on productive failure, desirable difficulties, and preparation for future learning suggests that grappling with a problem, even unsuccessfully, can help prepare learners to learn more deeply from other instructional materials or direct instruction, because such an experience activates prior knowledge and shows why the learning content is relevant (Kapur, 2016; Schmidt & Bjork, 1992; Schwartz & Bransford, 1998). Alternatively, when direct instruction precedes inquiry learning it can equip students with the required prior knowledge (Barzilai & Blau, 2014; Kollöffel & de Jong, 2013; Martin & Evans, 2019) and skills (e.g., Martella, Klahr, & Li, 2020; Yannier, Hudson, & Koedinger, 2020) or expose them to a different view of the domain before exploring it (Wecker et al., 2013). Wecker et al. (2013) also elucidated that telling before inquiry is can be important when the domain includes multiple latent entities having complex interplay. As another option, direct instruction can be provided to students "just in time." For example, Rieber, Tzeng, and Tribble (2004) found that students who received explanations during their interaction with a physics simulation outperformed students who did not receive these explanations. Lazonder, Hagemans, and de Jong (2010) reported beneficial effects of providing students with domain information before and during an investigation as compared to studying that information only beforehand or not at all. In a recent study, van der Graaf, Segers, and de Jong (2020) presented students with informational texts alongside a virtual lab. These authors found, based on eye-movement data, that students who scored higher on integrating the text and the virtual lab also performed better experiments; however, this association did not translate into higher learning gains for students with higher integration scores.

Another rationale for particular combinations of direct instruction and inquiry is that direct instruction without sustained engagement and practice is insufficient for robust acquisition and maintenance of learning over time (Dean & Kuhn, 2007). These findings align with work on desirable difficulties (Schmidt & Bjork, 1992) and classroom research in which direct instruction led to fewer errors during learning, but ultimately turned out to be less effective on delayed assessments (Vitale, McBride, & Linn, 2016). Thus, direct instruction requires subsequent sustained practice, typically involving some form of student inquiry to produce durable understanding. In planning these practice opportunities, the orchestration of direct instruction and inquiry-based activities is more effective when adapted to students' capabilities (Bell et al., 2005; Hmelo-Silver et al., 2007; Lazonder & Harmsen, 2016).

Regarding inquiry skills, Lazonder and Egberink (2014) demonstrated that being taught the CVS beforehand is just as effective for an upcoming inquiry as providing scaffolded help during the inquiry, while Eckhardt, Urhahne, Conrad, and Harms (2013) found that offering multiple scaffolds at the same time can be counterproductive for learning. Thus, the precise conditions that determine the effectiveness of certain combinations for acquiring inquiry skills are complex (see e.g., Newman & DeCaro, 2019). More research is needed to unpack what combinations of inquiry and other pedagogical approaches, including direct instruction, are best for whom, and at what point in the learning process.

6. The future of classroom instruction

From the evidence presented above, it is clear that guidance is (initially) needed to make inquiry learning successful. There are also indications that guidance is most effective when it is personalized and adaptive (Fukuda et al., 2022; Linn, Donnelly-Hermosillo, & Gerard, 2023). Guidance can be given in person by classroom teachers, but this poses challenges, because teachers often lack the time to perform a real-time diagnosis of every student's individual learning processes and give adaptive feedback. Technology support can alleviate these practical problems (see e.g., de Jong, 2019; Gerard & Linn, 2022; Graesser, Sabatini, & Li, 2022; Saleh et al., 2020). Currently, comprehensive collections of online labs/simulations that may form the basis for digital inquiry-based instruction are available for inquiry-based learning in science domains, such as PhET (Moore & Perkins, 2018; Wieman, Adams, & Perkins, 2008), Olabs (Nedungadi, Ramesh, Pradeep, & Raman, 2018), Molecular Workbench (Xie et al., 2011), ChemCollective (Yaron, Karabinos, Lange, Greeno, & Leinhardt, 2010), WISE (Slotta & Linn, 2009), Inq-ITS (Gobert, Sao Pedro, & Betts, 2023; Gobert, Sao Pedro, Li, & Lott, 2023; Gobert, Sao Pedro, Raziuddin, & Baker, 2013), and Go-Lab (de Jong et al., 2021). In such digital inquiry learning environments, students' log files (see e.g., Gobert et al., 2013; Greiff, Molnár, Martin, Zimmermann, & Csapó, 2018; Teig, Scherer, & Kjærnsli, 2020) or digital products such as hypotheses (Kroeze, van den Berg, Veldkamp, Lazonder, & de Jong, 2019) or concept maps (Kroeze, van den Berg, Veldkamp, & de Jong, 2021; Ryoo & Linn, 2016) can be used to monitor students' learning behavior and provide students with automated feedback.

A next step is to use artificial intelligence (AI) techniques to refine the delivery of more adaptive and personalized guidance (Dai & Ke, 2022; Li et al., 2019; Linn, McElhaney, Gerard, & Matuk, 2018; Luan et al., 2020; Wiley, Dimitriadis, Bradford, & Linn, 2020). For example, Yannier et al. (2020) developed a system that is able to diagnose elementary students' hands-on experimentation through visual algorithms based on camera data. Based on these data, an avatar guides the students in their inquiry by asking them to predict the results of an experimental set-up (e.g., Which tower will fall?), giving students feedback on whether their predictions match the outcomes and on students' explanations of the outcome (e.g., "because it has a narrower base", "because it has more weight on top"). In this example, students learn scientific principles of balance without any up-front telling of those principles. Gerard and Linn (2022) described a system based on natural language processing that can help students improve their scientific explanations in an inquiry context. In a meta-analysis involving 41 studies and 57 independent effect sizes, Gerard, Matuk, McElhaney, and Linn (2015) reported that automated, adaptive guidance was more effective than typical classroom guidance ($g = 0.34$). Linn et al. (2023) illustrated how the WISE authoring and customizing environment supports designers to personalize activities, guidance, collaborative experiences, and a teacher dashboard to make science instruction more equitable. Gobert and colleagues (Gobert, Moussavi, Li, Sao Pedro, & Dickler, 2018; Gobert, Sao Pedro, & Betts, 2023; Gobert, Sao Pedro, Li, & Lott, 2023) reported on Inq-ITS, which is an AI-based system that guides students in their inquiry process using virtual laboratories. In Inq-ITS, a digital agent named Rex provides scaffolds to students on a variety of inquiry skills when Inq-ITS' algorithms detect that they need help. These AI-based scaffolds have shown demonstrable efficacy for helping students learn many inquiry skills and transfer them to other science topics over long time periods (Li et al., 2019).

Another approach is using AI techniques to advise teachers (Mavrikis, Geraniou, Gutierrez Santos, & Poulovassilis, 2019). For example, Käser and Schwartz (2020) used log-files to infer students' inquiry strategies and determine their effectiveness. This information was then visualized in AI-based dashboards that could inform teachers about their students' inquiry strategies, so that teachers knew when and how to intervene. Similarly, Inq-ITS provides teachers with a dashboard called Inq-Blotter, which alerts teachers as to which students are struggling during an inquiry, how they are struggling, and how to help them (Gobert, Sao Pedro, & Betts, 2023). Dickler, Gobert, and Sao Pedro (2021) showed that students' inquiry performance improved on their next inquiry task for the skill for which they got teacher support based on alerts using Inq-ITS and Inq-Blotter. Thus, by using AI techniques it is possible to diagnose when students need specific domain knowledge or when inquiry processes should be scaffolded and then to deliver the needed guidance in an automated and just-in-time way via the teacher.

7. Conclusion

Overall, the literature persuasively shows the benefits of inquiry-based instruction over direct instruction for acquiring conceptual knowledge. However, a number of studies (including several program-based studies) did not find a difference in effectiveness between the two approaches. In this article we have mainly focused on conceptual domain knowledge as the outcome of the learning process. However, inquiry-based instruction may have a number of additional learning outcomes that are worthwhile for students, such as knowledge of the nature of science (Lederman, 1992; Schwartz, Lederman, & Crawford, 2004) and facility in other epistemic practices (Chinn & Duncan, 2021). Inquiry learning is also associated with higher interest in and enjoyment of science (Cairns & Areepattamannil, 2019) and higher self-efficacy (Liu & Wang, 2022). Being involved in inquiry learning may also be better preparation for future learning than following direct instruction (Chin et al., 2019). Finally, inquiry learning is very naturally situated in a collaborative community setting (Chinn & Duncan, 2021), in this way helping students to develop valuable collaboration skills (e.g., Eshuis et al., 2019; Puntambekar, Gnesdilow, Dornfeld Tissenbaum, Narayanan, & Rebello, 2021; Saleh et al., 2020).

We also indicated that there are a number of factors that may moderate the effect of an approach. In addition, even if one approach were always superior to the other, it would not seem advisable to make the curriculum fully dependent on that approach, if only to give students some variety in their learning activities. We have also seen that different instructional approaches are often combined in practice and that given the many independent dimensions of instruction that have been experimentally explored, a large variety of alternative forms of instruction exist (cf. Koedinger, Booth, & Klahr, 2013). Within such complexity we cannot expect to find a single clear and uncontested dividing line between direct instruction and inquiry-based approaches, especially because both approaches usually contain active components. Active learning seems a key condition for successful learning (Freeman et al., 2014; Yannier et al., 2021). Further, combinations of direct instruction and inquiry may be a fruitful approach, both in a specific learning unit and in a curriculum. One underlying premise, of course, is that the instruction (be it direct or inquiry-based instruction) must be well-designed and support students in their self-directed learning process. Digital instruction based on AI techniques may help create these effective designs. In summary, what may be the best guideline for design and future research was already offered by Alfieri et al. (2011):

> Perhaps the findings of these meta-analyses can help to move the debate away from issues of unassisted forms of discovery and toward a fruitful discussion and consequent empirical investigations of how scaffolding is best implemented, how to provide feedback in classroom settings, how to create worked examples for varieties of content, and when during the learning task direct forms of instruction should be provided. (p. 13)

Our analysis shows that policy reports that emphasized the value of inquiry learning are well founded, contrary to the arguments of Zhang et al. (2022). Indeed, the balance of the research demonstrates that using inquiry-based instruction (including guidance) as the core approach is either more beneficial than or equivalent to learning centered on direct instruction. The policy reports and the policy makers who followed these reports got it right when they adopted standards encouraging inquiry-based instruction.

Data availability

No data was used for the research described in the article.

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