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Original Paper

Decomposing the Cognition-influential Aspects of Instructional Designs A Systematic Review of Induced Causal Relationships by the Constructional Components of the Direct Instruction and Productive Failure Designs

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Abstract
A substantial debate on the effectiveness of two instructional designs, namely "Productive Failure (PF)" and "Direct Instruction (DI)" has been prolonged for almost two decades. Indeed, from many studies we have seen if being deliberately designed and carried out, then both designs can be sophisticated not only in instructional procedures but also in how each function takes effect on learning. The constituting components could each be specified preceding the instruction as a design, but these activities carry its own goal in facilitating learning. In this article, we summarized the reasoning in the specifications of connection, construction and criticization. Thus, from our review, we debated how instructional stages, problem-led learning and failure-driven learning can each deliver good outcomes for learners.

Keywords
productive failure, direct instruction, learning stages, self-explanation, conceptual change, failure-driven learning

1. Introduction

Though there is a rich source of investigations about the mechanism and result of the instructional designs "Productive failure" and "Direct instruction", we should emphasize more that designs themselves have involved multiple goals and multiple activities.

"Complex learning tasks and environments—particularly those implementing problem-based learning or inquiry learning approaches—usually require learner participation in various learning activities

with different specific goals that could be different from the immediate acquisition of domain-specific schemas." (Kalyuga & Singh, 2016, p. 834)

Hence, from the perspective of cognitive psychology and cognitive neurobiology, we appeal to disjunctively evaluate the underlying functions, goals, approaches, and effectiveness of the activities. The effectiveness of instructional design lies underneath the summation of every specification within the design. Interpret empirical results from a sophisticated instructional design involving multiple activities and goals would lead to the loss of focus on the original discussion upon any ascertained beneficial learning outcome.

That infers the comparison between "Productive failure" and "Direct instruction" should not be limited to comparing the overall learning results, mainly because the dependent measurements were too subjective, global, retrospective, turbulent, and harmonic to be steadily taken as a futural indication for the effectiveness of learning. One can extract four pairs of instructional ideology competition from a comparison between the instructional designs of "Productive failure" and "Direct instruction", namely a failure-based instruction versus plain message inculcation; uncertain problem-driven learning versus a reduction of learning procedures; a puzzling exploration versus passive absorption of knowledge (Laurillard, 2013; Mor & Craft, 2012); and it might just be a competition of instructional sequence (Loibl et al., 2017; Stockard et al., 2018). Conventional studies use empirical data in illustrating one or a few results among these competitions to infer the preponderance, however, because of the participation of various learning activities, to prove the superiority of any one of them needs to separately answer for each of these competitions. In negotiating the benefits of instruction, one should take more perspective from a cognitive point of view to express how the expected learning is constructed. Roth (1963, as cited in Seel et al., 2017) specified eight categories of learning goals, in the debate of instructional fulfillment, shall the goal and learning fulfillment need to be clearly stated and manifested to justify its success.

2. Connection

Both "Failure-driven" and example-instruction designs, if to be implemented successfully, demand the ability to trace and attribute back and forth, internally represent and organize knowledge relationships, a termed ability called "structural understanding" (Hiebert & Carpenter, 1992). To a minimal extent, it needs to induce the formation of subconscious impressions toward subsequent perception (Hamilton et al., 1980) and in guidance of the perception (Chartrand & Bargh, 1996) during the instruction phase. The crosstalk between activities by identifying the involuntary application of the mapped Stimulus-Response (S-R) rule is in supportive of it. Similarly, congruency between tasks would speed up response performance (Meiran, 1996). A prerequisite of 'linkage' is its correctness (Burke & Kass, 1996). So just verifying the capability of the brain to produce impact is not sufficient, we also would need to understand how the impact is linked.

A typical illustration of the functionality of linkage is “self-explanation”. “Self-explanation” is a critical process for promoting transfer (Aleven & Koedinger, 2002) or the learning of canonical procedures (Pine & Messer, 2000). The amount and quality of self-explanation are facilitative for the acquisition of cognitive skills (Siegler, 2002). A provision of cognitive or meta-cognitive (facilitation upon self-explanation) scaffolding is beneficial (Holmes et al., 2014; Loibl & Rummel, 2014). Here the ‘self-explanation’ could also signify a much implicit and non-verbal process in which the brain automatically fills in any missing concepts or experiences that were previously acquired. It evokes the meta-cognitive construction of knowledge. Learning is dependent on individual understanding of problem-related fields and thus builds fresh causal relation logic.

The investigation of the “Self-explanation effect” has exhibited that the constitution of self-explanation includes awareness of self-knowledge, and analogies to refer to previously learned knowledge (Chi & VanLehn, 1991). When learners encounter an impasse, the use of self-explanation enables them to acquire domain knowledge (VanLehn et al., 1992). Bielaczyc and colleagues (1995) reasoned the mechanism for self-explanation typically connected the observations or attempts with the concepts and used strategies in interpreting and elaborating the instructional contents into a more integrated and coherent form, or a disposition in perception. They reasoned the facilitative function of self-explanation: “(a) concepts and procedures are more memorable because multiple retrieval cues exist; (b) specific memories are created that match the conditions of use for a problem-solving skill (e.g., goals achieved by the skill, contexts in which the skill applies), and (c) inferences about and applications of a skill in new contexts are more easily accomplished because the self-explanations make explicit the underlying rational for the skill (p. 248)”. The presence of previous knowledge and observations are supportive, meta-cognitively the brain takes the aid by the cue to locate any useful piece of information to fill in the gap between the problem state and the current state, and hence any processing of knowledge utilizes the process of implicit self-explanation to call back many foreshadowing information, and hence they could be integrated into a large knowledge chunk, which essentially has many underlying concepts.

3. Construction

Prior knowledge is an interface for the clashing of the schemas. An activation of schema signifies the access of the prior knowledge and the process of storage or retrieval (Sweller, 1988). Generating a solution on one’s own is based on the activation of the prior knowledge (Loibl et al., 2017). The access process to prior knowledge to modify or utilize is different from its initial encoding (Hampshire et al., 2019). Schemas need to be integrated, competed, interlinked, and self-generalized when it comes to its activation. The process of brainstorming reveals learners accesses any available knowledge, make use of what has come to be activated, and then actively modifies it via all kinds of accessibility to the schemas (Kapur & Bielaczyc, 2012). What has been activated would decide the learners’ perspective of the material, in explaining the importance of prior knowledge for expertise, simply lack of prior knowledge makes learners lose some perspectives, or the capacity to generate some of those more efficient activation links, which resembles how the experts would see it (Chi et al., 1988). Letting learners to problematize will provide an opportunity for learners to recognize potential accessibility of previously acquired schemas. Being exposed to too much information at too early a time point is believed to hinder the learners' inquiry (Hiebert et al., 1996) since it reduces potential approaches the brain acquires another approach to access schemas. For example, the black and white discrepancy on a chessboard may provide little aid to novices, yet for the experts, it provides extra strategic value by exhibiting which of all the opponent's pieces are within a range of easy approaches. "Residue" refers to the remaining form of approaches to the schemas or schemas themselves that failed to be acquired (Davis, 1992), it defines the scale of utilization of schemas. A singular problem would only provide a narrowed scope of problem which needs few schemas and a shallow utilization of it. But multi-ends problematizing process would allow learners to inspect the accessibility more thoroughly, for example to establish the understanding of one concept by the analogy of another concept that was never thought of, thus filling up the potential residues.

Layperson always would have their initial naïve schema to alter from, typically when presented with an abnormality or conflict (Mortimer & Machado, 2000). So, the knowledge intaking is not a process of information intaking but to reconstruct by using preexisting schemas, to reestablish its logical pathways. Skills are merely taught to be re-applied in novel areas, a change of accessibility, instead of the skills themselves being taught (Youseff-Shalala et al., 2014). Instruction is to develop learners' knowledge in conformity with masters or scientists. However, the process of how a novice learner would change their original concept and construct upon it is even more complicated, for the evidence from the resiliency of the mistaken concept (Kozhevnikov & Hegarty, 2001). Artificially inserting schemas without establishing a good foundation for it to construct interlinkage and integration can lead to a devastating interference, because of its resilience, a factitiously introduced early concept can also restrain the subsequent concept the learner ought to be able to derive from instruction (Dunbar et al., 2007). New knowledge assimilation would interfere with earlier knowledge if the prior knowledge were incompatible with the new knowledge, by investing their meta-cognition (Prediger, 2008; Müller et al., 2008).

The comparison of apprentices and experts shows that the deviation is either caused by their possession of prior knowledge (Larkin et al., 1980; Chi et al., 1982) or caused by some domain-specific cognitive functional differences, such as more advanced inhibition to the competing options than novices (Dunbar et al., 2007), easier in recognizing the gap to the canonical solutions (Eva & Regehr, 2011), more capable in attend to the deep feature of a problem (Chi et al., 1982), and more automatic activation of schemas. Novices observe and imitate an expert role model (Bernieri, 1991). As a result, learners' original schema is rewritten and reconstructed to interact with the new knowledge system and produce a difference and contrast with the original schema structure.

Some argue the activation and access of schema is through implicit automatic activation of episodic memory causing learners to extract previous observational experience rather than the information itself (Schmidt et al., 2016). The resilience of learning does elicit the concern that for instruction, what could have been done to ascertain the activation and access to the schemas, when it comes to use, specific target content and interlinkage can be evoked or at least to be tracked.

4. Criticization

"Problem-Based Learning (PBL)" design involves the instructor's guidance, such as clarification, emphasis, elaboration, or hints (Puntambekar & Hübscher, 2005). It gives just-in-time support in learners' problem-solving (Wood et al., 1976) to foster successful problem-solving. It also induces curiosity (Sinha, 2022). Enhancing the resemblance of the self-generated solutions with the canonical solution, typically evoked by guided problem-solving, is bonded with the benefits of learning (Wiedmann et al., 2012). Some argue that the guidance in PBL curtailed any suboptimal solutions learners may develop, so more or less comes at the expense of the depth of the learner's solution (Kapur, 2016; Soderstorm & Bjork, 2015). Another argument is to devote to make the failures that can occur in problem solving revealed as much as possible, and to make allowances among instructional designs for these failures.

"PS-I designs are usually aimed at introducing new concepts to novices in a domain. Therefore, they typically have high failure rates even without any failure-scaffolding. This naturally leads to the question of whether there is an added efficacy of explicit scaffolding prior to instruction. (Sinha & Kapur, 2021a, p. 1)"

The conjecture of whether difficulties, with a by-product of confusion, are detrimental or beneficial is still ongoing even to this date (Arguel et al., 2017). Success-driven scaffolding during problem only withstand a short-term privilege (Kapur, 2011). The theory of 'Desirable difficulties' (Schmidt & Bjork, 1992) states that during the initial learning, increasing the complexity or variability of tasks, issuing problems in an unguided situation, or withdrawing the feedback a learner ought to receive: these approaches seem to hinder learning outcomes at first blush, but could be beneficial for longer-term (Kapur, 2016). Difficulty in problems can enhance learning outcomes (D'Mello et al., 2014). A perception of difficulty or confusion can trigger more active rethinking of strategies or to sort out the obstacles (D'Mello & Graesser, 2012). A framework called the zone of optimal confusion (ZOC) was raised by Graesser (2011) for negotiating the essentiality of restraining the difficulty within a range. A difficulty is designated to facilitate the building of sophisticated understanding (Kennedy & Lodge, 2016).

Some easy abilities such as adding and subtracting multidigit numbers can be conducted without explicit instruction, this infers a potentiality among learners called "Derivational knowledge" (VanLehn et al., 1992). Learners can still execute a procedure and perform tasks even if they do not understand (Hiebert & Wearne, 1997). And such a capability fulfilled the basic need within a difficulty-provoked problem-solving task, to generate a needed solution even before any engagement with some of its relative concepts (Klahr & Nigam, 2004). Learners have the capability to generate solutions, as shown in Lesh and Harel (2003), scilicet the capability to initiatively construct knowledge (diSessa & Sherin, 2000). However, generally thinking of a solution in solving the problem doesn't necessarily imply they can detect the underlying model (van Joolingen et al., 2005), and learners invented solutional procedures have a high potential of being flawed. Witnessed benefit from unguided problem-solving may be caused by an active interaction and processing of problem components, rather than caused by failure (Loibl & Rummel, 2014). Hence the use of guidance is to ensure learners not only can come up with a solution but can also make sense of it.

Even if we can resolve the essentialness of guidance or not, a major "doable" question remains for the failure-drive problem-solving technique. It first needs a settlement in whether a learner who came up with a suboptimal solution can be regarded as failed if they believe it is the optimal one. Then, it is noteworthy that having in one's mind that a solution is already been found, is very controversial with the idea that one is not be able to achieve the requirement of a problem, which is to generate a solution. If told being failure, then it would be another issue to discuss how come the generation process would just stop there and accept a doomed failure, instead of rather to keep on looking.

Interpretation of the mechanism of failure helps to understand its necessity to be embedded in problem-solving. Failure could help learners comprehend things that are not immediately apparent through self-explanation and reflection (Sinha & Kapur, 2021b). Pyc and Rawson (2010) proposed the role of earlier-occurred errors as a midway beacon for learners to follow the lead from the correct procedure and save some of the dead-end competitive steps. Hence only objective-related failures instead of the irrelevant failures can cause aid to subsequent recall (Huelser & Metcalfe, 2012; Grimaldi & Karpicke, 2012). Failure would facilitate the retrieval of both the episodic experience of the correct answer and the wrong one (Jacoby & Wahlheim, 2013). The novelty part of failure-causing rationale would be regarded as a 'remanent' factor if mismatched again with the representation (Öhman, 1992), then regardless of the portion already being corrected, the remainder would still call for correction. That is to say, if learners get to remember in the first place the notion that 'there has been a need for correction' from their previously believed-in concepts, more likely they will encode the information that follows (Wahlheim & Jacoby, 2013). Just like the argument in 'prediction error' which noted that a discrepancy between the learner's expected result of a solution/answer and the actual answer is key to drifting the attention toward the unexpected gap in-between (Lodge et al., 2018).

Rather than a failure situation, facilitating learners towards a suboptimal solution instead of an optimal one caused better conceptual understanding (Sinha et al., 2021). Because of the help-seeking characteristics of learners, hence, the learner may as well skip any profound failure-driven exploration, and deep thinking as well, but directly skip to the instruction. Therefore, it might be as well effective to deliver the suboptimal solution as a compensation. Another possible maneuver is to explicitly encourage learners themselves to make mistakes, meta-analysis has revealed the advantage of such intervention in transfer (Keith & Frese, 2008). Both approaches seemly have opened the scope of failure-driven scaffolding rather than the conventional negative disdain of the process of making the error.

5. Conclusion

Just as we demonstrated, there remains much to debate in the specification of instructional design. By the view from the cognitive psychology, before we implement an ecological experiment, many has to be reasoned and verified. In this article we introduced how is that possible that multiple-stage instructional design would elicit learning effect of its own; how the storage and accessibility of schemas are in accordance with the constructed chain of activation, maybe it is attributed to the expertise of the learners, but it could also be from the instruction: problematization elicits an expansion of the accessibility network of the schema; and how the failure and difficult induced for the purpose of confusion would impact on learners' experience. The topics we have covered is merely a small portion of the designated specifications among the 'Productive failure' instructional designs. We argue that if one bears a purpose to convey the benefit of the "Productive failure" instructional designs, or in fact any kind of instructional design, then there is must to decompose the specification into smaller cognition-inducing units, to first make clear what could be expected if, not the switch of entire type of instruction, but merely addition of the small change in learning, could bring forth to the learning. Nevertheless, in this article, what we actually discussed is still very insightful to persuade the "Productive failure" design, the unique view angle permits us to convey a more detailed persuasion: learners extend their self-explanation in a two-stage instruction, what is experienced during free exploration makes foundation for the instruction stage, when the instructional given, any unclearly delivered knowledge can be compensated by learner's inner tracing back to the observation during problem-solving stage; rather than simply absorbing the knowledge, problematizing it allows learners to expand the use of knowledge, generate more analogies, and thus extend the potential accessibility of the schemas; learners could generate useful thoughts in spite of difficulties, to facilitate the learner during their problem-solving is at a cost. However, failure experience is not an easy specification to implement, a major problem is the contradiction between failure and the perceived successfulness in finding any solutions. It is possible that failure-driven benefit is just superficial, a flawed and scripted sub-optimal solution does not necessarily bring about just the awareness of knowledge gap. Therefore, we appeal that more insights are needed from futural studies.

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