Understanding Learning in an Online Environment

Course Essay, April 2019

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Understanding the role of productive failure in the learning process.

Word count: 2742

Before we start, can you guess the meaning of the following Japanese ideograms?

子

日

木

犬

女

Check your answers on the next page. Were you successful or did you fail?

As[1] teachers, we want our students to succeed. Much of our work goes into thinking about how we can help them better understand, we scaffold their learning, structure the problems, model solutions, offer practice exercises, plan hands-on experiments, etc. We want them to do well and avoid failure so that they don't loose confidence in themselves or motivation to continue learning. However, learning implies going beyond what we can currently do, risk taking, and therefore often initial failure. If we do not want to limit our students' learning, we need to make failure acceptable and possibly even an integral part of the learning process.

In the first part, I look at how teaching theory and practice have often led to minimizing failure and structuring for success. We will show that, while these are important considerations to keep in mind when designing for learning, they do not necessarily exclude the experience of failure. In the second section, we consider the research on productive failure and how failure can support learning. Although the research on productive failure is substantial, the theoretical explanations are often partial. I attempt to give a more complete view of the cognitive effect of productive failure.

Should failure be avoided at all cost?

According to the Oxford Dictionary, failure is the 'lack of success' and success is the 'accomplishment of an aim or purpose'. Clifford (1984, 109) then defines failures as 'a performance-goal ratio of less than one ($F=P/G<1$), that is, the goal is greater than the performance. Success is then $P/G \geq 1$, 'an event in which a goal is attained or surpassed'. To measure failure or success we need a measurable goal, goal awareness, a performance and its evaluation and finally a comparison between the goal and performance. This means that success or failure depend on who determines the goal and how the performance is measured, as in our initial ideogram test. These may not be considered objective, and the student and teacher may consider them differently.

Letting students discover on their own, and therefore often fail, has been shown to have lower outcomes for students than direct instruction. Klahr and Nigam (2004) carried out an

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[1] 子 (child) 日 (sun) 木 (tree) 犬 (dog) 女 (woman). Here are a few more ideograms that may be fun to remember: 山 (mountain) 好 (love) 大 (big) 月 (moon) 川 (river)

experiment on school children on the control of variables strategy principle through a hands on experiment. The students were first assessed through a discovery session without guidance, followed by either the continuation of the unguided problem-solving approach, or direct instruction. Finally, all students were assessed. The outcome was clear: 77% of the direct instruction group showed a good mastery of the concept, compared to 23% in the unguided group. Krischner, Sweller and Clark (2006) relate this to our limited amount of working memory, so that non-guided problem based learning quickly leads to cognitive over-load, especially in the case of novices. Moreover, as the working memory is fully occupied, it is not available to process the new information into the long-term memory. Worked examples, for example, help overcome the cognitive load issue, while also reducing the risk of mistakes or going down an unproductive path. The benefit of direct instruction and importance of not leaving students without any guidance appears clear.

However, this does not imply that there is no space for discovery and possible failure. In Klahr and Nigam's (2004) own research, the initial step is an unguided exploration phase, with low overall performance by the students. Rather than just a base line, this first part of the experiment should be considered an integral part of the learning experience. As we will see, further research comparing groups with and without the exploration step give very different results. However, before discussing this research, we consider the possible negative effect of failure itself.

Failure itself can have negative consequences on learning as it has been shown to lead to demotivation, due to learned helplessness, low self-confidence or low self-efficiency.

According to Ryan and Deci (2000), intrinsic motivation may be undermined if a person does not feel competent such as when the challenge is too high and if the person does not feel a sense of autonomy. A fail or bad grade may make a student feel incompetent and therefore demotivated towards future learning. As reported by Clifford (1984, 110), low performance has been correlated to reduced self-confidence, unhappiness, and lowered aspirations. These are clearly outcomes we want to avoid.

However, looking more closely, these negative outcomes appear under specific conditions of attribution. When failure is attributed to factors that cannot be changed by the performer such as lack of ability or appear random, then he or she may feel helpless. In this case, a low performance often leads to giving up (Diener and Dweck 1978). When children were told their low performance was due to lack of effort, following performance improved. Therefore, rather than avoiding failure, attributing it to something the performer can control is important, as mastery-led students do naturally. Clifford (1984) suggests that rather than lack of effort, attributing failure to wrong strategies would be more beneficial. ‘They allow one to escape the guilt associated with not trying, and the embarrassment and shame associate with being stupid. But perhaps most importantly, strategy explanations tend to turn failure outcomes into problem-solving situations in which the search for a more effective strategy becomes the major focus of attention’ (1984, 112). This may lead to a greater effort and focus on finding a solution.

Finally, although failure is painful, we do not always try to avoid it, sometimes, as described by Juul (2013), we even seek it out. A game in which we would never loose, would not be worth playing. It is only through failure that we feel challenged to try again, improve our skills and finally win. ‘The paradox of failure: it is only through feeling responsible for failure (which we dislike) that we can feel responsible for escaping failure (which we like)’ (2013, 54). DiSessa described how motivation kept him experimenting despite ‘unpleasant feelings of frustration’ (2000, 84). We must differentiate between short-term frustration and long-term success.

Our above discussion shows that letting students learn without any guidance is not efficient and failure may even have very negative consequences on motivation and self-esteem. These imply a careful design of the learning process, but do not, *per se*, exclude failure as a learning tool. As described in ‘The Art of Failure,’ only through failure can we improve in video games (Juul 2013). Does this also apply to learning in an academic environment?

Can failure be an efficient learning tool?

In the previous section, the experiments focused on extreme cases: totally unguided learning vs. direct instruction, or mastery vs. helplessness. However, several studies have shown that there is the possibility of a productive middle ground. We first look at the results of these studies, before trying to explain why productive failure may be a useful tool in learning.

As mentioned in the previous section, Klahr and Nigam (2004) introduced a form of failure at the beginning on their experiment, asking all students to explore the concept and experiment instruments, leading to overall poor results (less than one unconfounded experiment per child on average). Did this initial exploration influence learning? Kapur (2011) tests this in an experiment with secondary school children learning about average speed. Kapur compares three groups: one with a productive failure part (unguided problem-solving group work, followed by individual work, then a lecture). A second group received a traditional classroom approach: lectures, worked examples and finally well-structured exercises. The last group was carried out as the first one, with complex problem solving, but this time facilitated throughout, followed by a final lecture. Before and after the experiment, students took a pre- and post-test (including well-structured problems, a higher-order application and items on tabular and graphical representation). The results show that the Productive Failure group scored the highest on all three aspects (well-structured and higher-order items as well as representations), followed by the facilitated complex problem-solving group and then the lecture-practice group. Although instruction does play an important role, preceding it with unguided problem-solving, often leading to failure, shows better learning than starting directly with the instructional part. Other experiments show similar results. Kornell, Hays and Bjork (2009) demonstrate the benefit of unsuccessful tests on future learning. Lai, Portolese and Jacobson (2017) apply the concept of productive failure to early-career engineers comparing the outcome of two learning sequences: lecture-exercise or exercise-lecture and show a significantly positive effect of initial failure (exercise first). Toh and Kapur (2017) find that low levels of pre-knowledge do not prevent productive failure.

How does productive failure affect learning?

The following analysis is based on the most commonly used Productive Failure structure of group work to generate solutions for a complex problem, without facilitation, followed by a period of structured consolidation and finally individual problem solving (Kapur 2008; Loibl and Leuders 2018; Lai, Portolese, and Jacobson 2017). I consider three main steps in the cognitive process of learning that are affected by productive failure: the activation of prior knowledge, the appearance of a cognitive dissonance and the period of structured consolidation.

Prior knowledge activation is important for three main processes: for the teacher to know where the students stand, as a basis for building understanding by the student and in developing a locale memory.

As Kapur points out, teachers need to know their students current understanding and this can only be done if it is made explicit by pushing students to their limit, and therefore fail to solve the problems (Kapur 2011). Teachers can then ensure that that the students are learning in their zone of proximal development and are not under challenged or over stretched (Vygotsky 2011; Csikszentmihalyi 2000). However, in Kapur's experiments, the teaching is not changed based on the outcome of the non-guided phase. The activation of prior knowledge is probably more important for the learning itself.

According to Piaget (2007), operative intelligence is responsible for creating schemas of the world and changing them as we perceive new information through assimilation and accommodation, and both are based on our existing view of the world. In the case of assimilation, new knowledge is incorporated into the existing schema. If we use a puzzle as a metaphor of building our understanding of the world, it would be adding a piece to the pieces we already have available (*Figure 1*).

Figure 1

However, when the new information does not fit the old schemas, then accommodation takes place (*Figure 2*). A previous assembly of pieces may need to be undone to make place for the new piece.

Figure 2

In either case, the existing knowledge needs to be activated to build on it, as when we look at the pieces of puzzle already available. Moreover, this problem-solving part may help students develop an intuition for the notion. For example, before learning about standard deviation, students were asked to rank baseball players for consistency, thus recalling the concepts of mean and deviation, despite not being able to correctly solve the problem (Kapur 2019). Once the teacher introduced the notion of standard deviation, they would already have an intuition or ‘feeling for’ concept (DiSessa 2000).

This retrieval also creates links between known concepts. On the one hand, this leads to deeper processing, strengthening correct routes, and weakening ones that do not lead to a solution (Kornell, Hays, and Bjork 2009). On the other hand, it participates in the creation of a locale memory. In the case of worked examples, students may gain knowledge of just one route. In problem-solving, students try a number of paths, some successful, some not, but create a map of complex relationships within the larger context (Caine and Caine 1994). In our puzzle metaphor, instead of the teacher showing the learner where the piece belongs and in which direction to put it, students try out different positions (*Figure 3*). While doing this, the specificities of each area are analysed, ever finer categories are defined (the forest, the field, the pond) and their relationships or differences are reinforced.

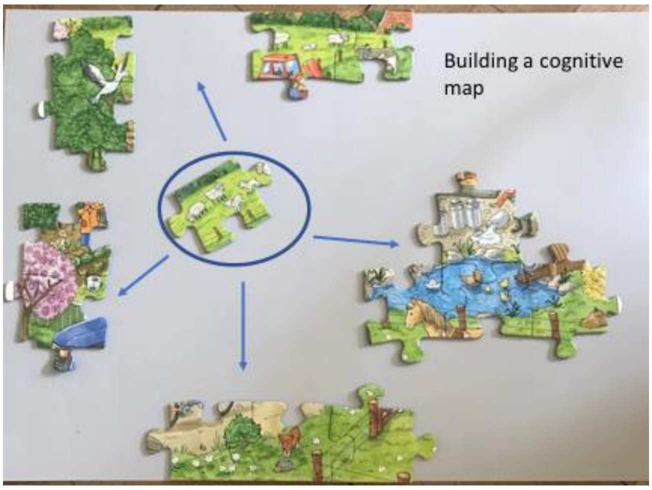

Figure 3

The activation of prior knowledge is essential for learning, to enhance existing schemas, transform them and build a cognitive map. Just as important is the role of failure itself in the learning process. I consider three aspects: the knowledge gap, cognitive dissonance and the unavoidability of failure.

Students may become aware of missing knowledge, or of a discrepancy between their current beliefs and the new information. In the first case, identifying knowledge gaps may create a teachable moment (Brown 2017), as students feel they need new information and become motivated by curiosity and expectations looking for the missing piece (*Figure 4*) (Caine and Caine 1994; Loibl and Leuders 2018).

Figure 4

Cognitive dissonance may be more threatening, but, as Piaget (2007) wrote, this feeling of disequilibrium is necessary for learning. Naturally, humans search for an equilibrium and therefore look to accommodate the new information into a restructured schema, striving for a newly constructed coherence. This often leads to more differentiated and complex conceptual structures, building towards a greater mastery (Kapur 2011, 562). In Lewin's framework for change, the failure leads to the unfreezing of current mind set (Lewin 1947).

Sometimes, we may not be able to avoid failure, as with threshold concepts. As Cousin (2006, 5) put it, 'mastery (…) involves messy journeys back, forth and across conceptual terrain'. Problem solving and productive failure can bring students into 'liminal spaces,' the unstable area between what is thought to be known and the emergent schemas. Just recognizing the fact that problem-solving and failure may lead to confusion and that it is an integral part of learning may help students through this uncomfortable period (Papert, 1996; in Kafai and Resnick 2010). Moreover, hearing the students' misconceptions is essential to lifting the confusion. Shanahan and Meyer (2006) show how 'locating the troublesomeness' amongst seven different types of mistaken knowledge (ritual, inert, conceptually difficult, alien, paradoxical, tacit or troublesome language) helps teachers gain 'insight into the *sources* of any (…) learning difficulties.'

With prior knowledge activated and facing a knowledge gap or cognitive dissonance, students are open to new concepts and to modifying their current schemas. However, as discussed in the first section, unguided problem solving alone does not lead to good performance. For failure to become productive, consolidation is essential. This may be done through lectures (Lai, Portolese, and Jacobson 2017), teacher-led discussions (Kapur 2011), but has also been successful in online environments (computer-supported collaborative learning, CSCL) with well-structured problems following the initial discovery period (Kapur and Kinzer 2009). Learning does not happen just through experience, but through the following reflection (Piaget 2007; Papert, 1996; Kayes, Kayes, and Kolb 2005), and comparing student findings with the canonical answers, ensuring that students can revise their mental model (*Figure 5*) (Loibl and Leuders 2018).

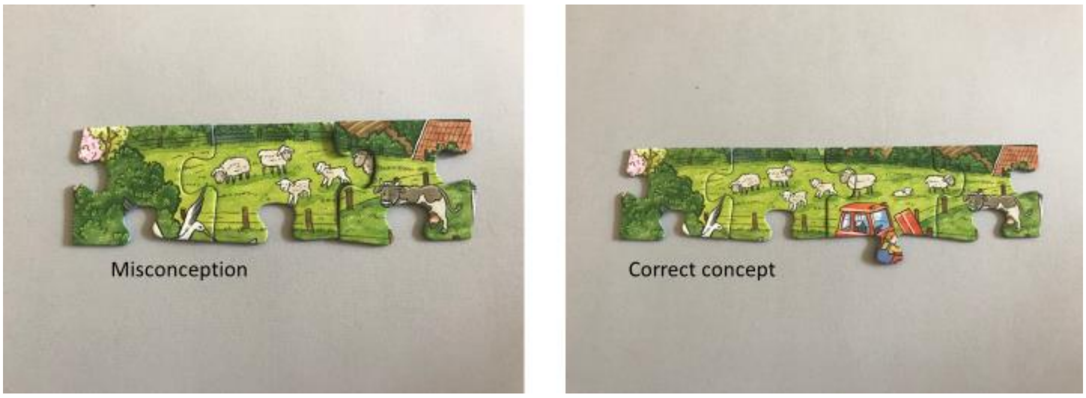

Figure 5

Conclusion

Real learning cannot happen without some element of failure. Failure plays an important role in creating awareness of knowledge gaps or misperceptions, motivating students to seek a new understanding. However, failure needs to be carefully designed into the learning process. Attribution of failure to something controllable such as effort, or better still strategy has shown positive results. The task should be within the Zone of Proximal Development, a balance between challenge and capability (Csikszentmihalyi 2000; in Clifford 1984, 115). There is, however, more research to be done on the value of group work in the problem-solving phase. To my knowledge, this has not been compared to with individual work conditions, which is an important element of the design. Most research has focused on mathematics and sciences, it would be useful to extend this to other fields, such as economics.

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If you 'failed' on the introductory test, would you like to see whether it was productive? Can you label these ideograms?

子

日

木

犬

女

山

好

大

月

川

The answers are on the next page. Did productive failure work better than direct instruction for you (the first five might have been an example of productive failure if you tried to guess the meanings but failed, whereas the last 5 are an example of direct instruction as I gave you the meaning)?

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[2] 子 (child) 日 (sun) 木 (tree) 犬 (dog) 女 (woman) 山 (mountain) 好 (love) 大 (big) 月 (moon) 川 (river)

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