Exploring the Solution Generation Process in the Problem-Solving Phase followed by Instruction: How Do Learners Perceive their Knowledge Gaps?

Jinju Lee, Hanyang University, leejinju@hanyang.ac.kr
Jongehan Park, Kwangwoon University, nmb0172@gmail.com
Dongsik Kim, Hanyang University, kimdsik@hanyang.ac.kr

Abstract: This study investigates how the awareness of knowledge gaps (AKG) manifests by observing the problem-solving phase in PS-I (problem-solving followed by instruction). Comprehensively exploring the discourses of learners in this phase while seeking to categorize knowledge states around AKG will strengthen the underlying mechanism of PS-I. Understanding how AKG manifests will help pave the way for further research on how various knowledge states influence the effectiveness of PS-I, facilitating the design of appropriate instructional interventions to promote desirable knowledge states. With twelve graduate students as participants, this study qualitatively analyzes conversational discourses of the problem-solving phase and finds that students spend most of their time solving problems and seldom evaluate their thoughts, while only a few express their experience of a knowledge gap. The authors suggest categories of knowledge states around AKG and the distinctive characteristics of each category.

Keywords: awareness of knowledge gaps, problem-solving followed by instruction, qualitative content analysis

Introduction

The learning approach known as problem-solving followed by instruction (PS-I) has emerged as an attractive research area over the last decade because it may offer students productive learning experiences regardless of their initial unsatisfactory performances (Kapur, 2016). Under the PS-I approach, instructional interventions promote the learner’s self-made tryouts (in the initial problem-solving phase) and use this experience to construct a strong schema that will be subsequently useful in the instruction phase (Likourezos & Kalyuga, 2017; Loibl et al., 2017). Research groups in productive failure and invention activity, which are strategies representative of the PS-I approach, have reported positive effects (Darabi et al., 2018; Loibl et al., 2017), with even more favorable effects emerging when compared to the instruction followed by problem-solving (I-PS) approach (Schalk et al., 2018).

What makes the problem-solving process in the PS-I approach unique compared to the conventional problem-solving after instruction approach? The review of Loibl and her colleagues (2017) described three mechanisms for how the external instructional event of PS-I triggers an internal state in the learner: a) prior knowledge activation, b) awareness of knowledge gaps, and c) recognition of the deep features of the target concept. The second mechanism, which is the focus of this study, is key to the efficacy of PS-I. The failure to solve a problem is ineffective if students are unaware of their failure because learners need to know what they don’t know to be better prepared for the upcoming instruction, both cognitively and affectively (Hmelo-Silver et al., 2018). Awareness of knowledge gaps (AKG), which is a main cognitive event during the problem-solving phase, is an important aspect of the PS-I approach as it relates to the use and elevation of meta-cognition, which plays a crucial role in complex problem-solving and knowledge construction (Likourezos & Kalyuga, 2017). The knowledge gap highlights what a learner lacks and thus needs to know, thereby making the failure experience productive. However, little is known about how to support AKG.

This study starts with curiosity, asking whether a student can reach the ‘knowing what they do not know’ state, and if so, how this AKG manifests and whether the learner’s state of AKG affects the effectiveness of PS-I. As a preliminary phase for the abovementioned research question, this study focused on how students become aware of their knowledge gap by exploring the process of problem-solving in PS-I in both deductive and inductive ways. Specifically, the current study first qualitatively examined learners’ conversational discourse in problem-solving during PS-I using a deductive content analysis. Then, the authors conducted an inductive content analysis with the same talk-aloud data to classify the knowledge states around AKG. Identifying the characteristics of each state facilitates the understanding of how learners experience their knowledge gaps and how AKG manifests during problem-solving through comparisons with other knowledge states. This understanding offers practical implications for research on scaffolding strategies for positive experiences around AKG in PS-I.
Awareness of knowledge gaps in the PS-I approach research

Among PS-I advocates, researchers interested in invention activity (see Schwartz & Martin, 2004) are those who conceptualized the idea of the knowledge gap and measured it with questionnaires. Glogger et al. (2013) focused on the experience of the knowledge gap as a cognitive outcome of invention activity and assessed it using nine items on six-point self-rated scales (e.g., “My knowledge was insufficient to complete the task”). Their results indicated that invention activity increased the knowledge gap. They used a five-item version in their follow-up study and reported the same result (Glogger et al., 2015).

Subsequently, Loibl and Rummel (2014) introduced the term ‘awareness of knowledge gaps’. The idea is rooted in the impasse-repair-reflect process (vanLehn, 1999) and the imperfect mental model view (Chi, 2000), which highlights the mental repair process of students when they become aware of their incapability in processing the incoming information within their current knowledge. Loibl and Rummel compartmentalized this awareness of incapability into a global awareness of knowledge gaps (i.e., “an awareness that they have knowledge gaps without being able to specify which component they are lacking”, p.75) and an awareness of specific knowledge gaps (i.e., an awareness elicited during instruction by “helping them to detect differences in a more specific manner”, p.75). They argued that identifying knowledge gaps may induce modifications to learners’ current partial, naïve, or erroneous schemas, and suggested that instruction that compares a student’s solution to the canonical solution can specify the gaps that occurred globally in the problem-solving phase. Using five items (e.g., “I lack knowledge required to solve this problem” and “I think I did not find a canonical solution for this problem”, p. 81), they demonstrated that a PS-I session can trigger global AKG, with students in the PS-I group reporting more knowledge gaps than those in the I-PS group. In their follow-up studies, they emphasized comparing and contrasting activities as a remedy in specifying the knowledge gap and a connector to the next mechanism (i.e., deep feature recognition) (Loibl et al., 2017; Loibl et al., 2020).

The idea of AKG is also supported by other advocates of the PS-I approach. In his comprehensive work on productive failure, Kapur (2016) stressed the importance of differentiating relevant prior knowledge and identifying knowledge gaps as mechanisms of learning through problem-solving (see also Hmelo-Silver, Kapur, & Hamstra, 2018). Using Glogger and colleagues’ (2015) questionnaire items, Lee et al. (2018) reported that supporting the problem-solving phase with meta-cognitive prompts increased AKG. Newman and DeCaro (2019) emphasized AKG as a metacognitive benefit of exploratory learning, providing guidance for students to perceive knowledge gaps. They examined whether students perceive knowledge gaps differently according to the order of instruction (i.e., instruction-first versus explore-first) and activity implemented (i.e., invention versus worked example). Finding evidence of a significant main effect and an interaction effect, they suggested providing pretests with worked examples as a supporting strategy for AKG.

However, the previous studies only dealt with global AKG using self-reported scales. Hence, how such awareness does, or does not, emerge during problem-solving is still not fully understood. As to the important role of AKG in the PS-I approach, instructional interventions for AKG arise as a remarkable research topic. In other words, the learner’s experience around AKG needs to be scrutinized: Is it enough to understand learners’ AKG as global AKG, or are there any other knowledge state categories around AKG? Why do some learners develop AKG, while others do not? This study investigates how AKG manifests by observing the problem-solving phase in PS-I. Comprehensively exploring the discourses of learners in this phase while striving to categorize knowledge states around AKG will strengthen the underlying mechanism of PS-I. Further, understanding how AKG manifests will open an avenue for future research to examine how various knowledge states impact the effectiveness of PS-I and subsequently design appropriate instructional interventions that promote desired knowledge states.

Research questions

1. What cognitive processes do learners experience when they assess the given problem and develop their own solution?
2. How do learners evaluate their knowledge during the problem-solving phase in PS-I?
3. How can the states of the awareness of knowledge gaps be defined?

Methodology

The main analysis method used in this study was qualitative content analysis. The advantage of content analysis lies in its ability to draw replicable and valid inferences from observed conversational discourses to their context (Krippendorff, 1980). Qualitative content analysis is an effective method for understanding and describing phenomena by creating or applying categories and concepts (Elo & Kyngäs, 2008; Mayring, 2000). Regarding the first research question, the authors first qualitatively examined learners’ conversational discourse in problem-solving in PS-I using deductive content analysis. With a coding scheme adapted and revised from previous
research (Poole & Holmes, 1995; Große & Renkl, 2007), students’ conversation texts were categorized into one of the codes.

Based on the implications from the first content analysis result, an inductive content analysis was conducted with the same talk-aloud data after defining different analysis units to answer the second and third research questions. The knowledge states around AKG were classified, and the authors categorized several variations of how the students self-evaluated their knowledge during problem-solving. In the process, the authors open-coded the discourse data and identified the characteristics of each state through comparisons between categories.

Material and participants
With the publisher’s permission, this study used the problem scenario from Kapur’s (2008, pp.419-421) work, which is ill-structured and carefully designed. The problem scenario encompassed investigating a speeding case, targeting the concept of frictional force and work-kinetic energy. The first author translated the problem scenario into Korean with an American English professor who is bilingual in Korean and English. After translating the problem, the validity of the material was confirmed by a high-school physics teacher. Twelve graduate students majoring in Educational Technology were recruited from a graduate school in South Korea (nine females and three males; average age = 25), who received $5 value gift cards as a reward for their participation. The participants were randomly assigned to one of six pairs.

Procedures and data collection
The experiment followed procedures in the conventional PS-I approach, i.e., peer problem-solving followed by instruction. The participants worked with iPad Pro 2s and Apple Pencils during the experiment session to record the dialogue and notes taken during the session. The default ‘screen recording mode’ was used to collect spoken and written data. For the problem-solving phase, the pairs of students were each given 25 minutes to collaboratively solve the problem scenario with a peer, sharing one iPad and one Apple Pencil (see Figure 1 (a)). After the problem-solving phase, the participants individually watched an instructional video that included a lecture on the target concepts and a solution explanation for the problem scenario. As they worked individually in the instruction phase, one iPad and one Apple Pencil were provided per student. The participants were asked to watch the instructional video on the left-hand side of the screen along with the scribbled version of the problem scenario file on the right-hand side of the screen; they were able to take notes over their previous notes if necessary (see Figure 1 (b)). The spoken data in the collected recordings were subsequently transcribed into script format and used for the dialogue analysis. The written data were used in a supplementary role in the analysis of the spoken data. This study mainly focused on the discourse data generated during the problem-solving phase. Investigating the effects of the PS-I approach (e.g., post-test results…etc.) was beyond our research scope.

Data Analysis
This study used two qualitative content analyses with the same conversational discourse data: Deductive content analysis to examine the cognitive processes or aspects that the learners experienced during problem-solving, followed by inductive content analysis to categorize the different states of knowledge and define each state through comparisons between categories. As the selection of the analysis units depends on what the analysis aims to discover (i.e., in relation to the research question; Mayring, 2000), the authors selected different analysis units for each content analysis.
Deductive content analysis for problem-solving discourse

The authors adapted two coding schemes used in previous studies on student interactions (Kapur & Kinzer, 2009; Poole & Holmes, 1995) and self-explanation in learning from erroneous examples (Große & Renkl, 2007), integrating them to ensure the integrated coding scheme was sufficient to achieve the current research aim. While the coding scheme from Kapur and Kinzer (2009) reflected the multifaceted nature of student interaction, it lacked separate room for impasse-related and error-related utterances. The coding scheme from Große and Renkl (2007) provided logical and clear distinctions between those utterances. As the current study aims to explore the cognitive processes that learners experience when they solve a given problem, the authors needed to differentiate from other categories such utterances that may show a cognitive trajectory towards a different knowledge state. As a preparation phase for the content analysis, the authors divided the discourse transcript into idea units, which were selected as including words or sentences containing a context for a meaning unit in terms of each category.

The authors then conducted a preliminary coding based on the adapted coding scheme, which included the categories of Problem Assessment, Orientation, Impasse, Solution Development, Recognition of Error, Identification of Reasons for the Error, and Solution Evaluation without Error Detection. During the preliminary coding process, new categories were found, namely Guess and Assumption, Prior Knowledge, and Motivation. After closely reading the discourse transcripts, it turned out that the learners often tried to make assumptions based on contextual information about the problem, such as “I think the coefficient of friction has something to do with the weight of the car”. This study created a new category for this sort of utterance, Guess and Assumption, because the authors believed that making assumptions could be a starting point for an awareness of a knowledge gap. Moreover, Prior Knowledge was added to the codes because the learners often retrieved relevant concepts when assessing the problem and generating and evaluating the solution. Aligning new information obtained from assessing the given problem with their prior knowledge can be a sign of learners revisiting their memory (Park et al. 2020) and preparing to generate a solution, which, in many cases, leads to global AKG (Loibl & Rummel, 2014). After learners realized that they needed more knowledge to solve the problem, some of them stated that they wanted to learn the need-to-know knowledge from the following instruction. The authors coded these utterances as Motivation. The first and second author then coded every idea unit based on the final coding scheme (see Table1). The inter-rater reliability was good (Cohen’s κ = 0.74), and the final code was determined by resolving any discrepancies through discussion.

Table 1: Coding scheme for problem-solving discourse

<table>
<thead>
<tr>
<th>Codes</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem assessment</td>
<td>Mentions details of a problem, prioritizes details, makes connections between details, or provides new perspectives in interpreting aspects of a problem.</td>
<td>“Um... For now, I think what counts is... the total weight and time, not the total weight and the speed limit. like we thought.”</td>
</tr>
<tr>
<td>Orientation</td>
<td>Tries to orient or guide the group’s process</td>
<td>“Let’s write down and then think about it”</td>
</tr>
<tr>
<td>Impasse</td>
<td>Expresses confusion, pauses for a long period, and/or states unexpected difficulty and negative monitoring</td>
<td>“Coefficient of friction... apply the coefficient of friction. Then the way is... (long pause)”</td>
</tr>
<tr>
<td>Solution development</td>
<td>Mentions a (sub-)goal, an operator, or a relevant formula, tries anticipative reasoning, and/or suggests ideas, proposals, alternatives, or rebuttals</td>
<td>“Distance 15, velocity 55. Shall we calculate the speed using distance velocity and time (DVT)?”</td>
</tr>
<tr>
<td>Guess and assumption</td>
<td>Guesses next solution steps, and/or makes assumptions on concepts and processes to assess a problem and generate and evaluate a solution</td>
<td>“But since high coefficient of friction means a stronger friction, doesn’t it mean the brake should work faster? That’s how I see it.”</td>
</tr>
<tr>
<td>Prior knowledge</td>
<td>Activates prior knowledge and/or aligns it with new information</td>
<td>“Suppose the distance is 15 meters, then, um, this is X and it would be best to know the acceleration inclination, mmm F= ma...”</td>
</tr>
<tr>
<td>Recognition of error</td>
<td>Mentions that there is an error and/or finds an error in the generated solution</td>
<td>“This is 4.5 again? Maybe not, I don’t think this is it, obviously, 559.”</td>
</tr>
<tr>
<td>Identification of reasons for the error</td>
<td>Gives reasons for the errors</td>
<td>“I think the coefficient of friction we set here should not be 1.”</td>
</tr>
<tr>
<td>Solution evaluation without error detection</td>
<td>Gives an evaluation of the generated solution (but does not find any potential errors)</td>
<td>“When we say this is 25, what’s the reason for dividing it with the weight? ... I mean we divided the total distance... right? I think what we did is right!”</td>
</tr>
</tbody>
</table>
An inductive content analysis for knowledge state categorization during problem-solving

During the course of applying the deductive approach, new categories of the problem-solving discourse emerged in regard to learners’ attempts to guess the next solution steps, prior knowledge alignment, and motivational aspects. The authors were able to identify that the utterances of these categories were presented by some participants but not all participants. Based on this finding, the authors conducted the second content analysis in an inductive manner to explore how the learners’ knowledge states varied in the problem-solving phase of PS-I.

A new selection of idea units for the analysis with the same discourse data was made because the aim of the second content analysis was different from that of the first analysis, namely to analyze how learners evaluate their current knowledge and to define the states of AKG. Knowledge states in an individual learner may vary depending on different related concepts. Thus, an idea unit was selected if it included phrases representing a knowledge state around each related concept (e.g., kinetic energy variation, work-energy relation, friction).

After identifying all idea units, the first and second author conducted open coding. During the process, the coders suggested a total of eight categories, namely, a) Knowledge not Accessed, b) Knowledge not Evaluated, Knowledge Evaluated as c) Sufficient, d) Intuitive, e) Naïve, or f) Uncertain, g) Insufficient and Unspecified Knowledge Gaps, and h) Insufficient and Specified Knowledge Gaps. The coders then assigned idea units to these categories. In the discourse, explicit signs of self-evaluation (e.g., “I think we were wrong here”) were rarely presented, although some remarks (e.g., “If I know the formula to use this...”) could be indirectly inferred as self-evaluation. The coders used these signs as criteria to determine whether parts of the discourse belonged to self-evaluation. During the course of the preliminary coding, the Intuitive category was removed because self-evaluating their own knowledge as intuitive was always involved in parts of either Sufficient, Naïve or Uncertain (e.g., “This reminds me of energy because everything has energy, but I don’t know whether we are on the right track. Do you?”), but not vice versa, in the data collected. In a similar vein, the coders agreed to integrate Naïve and Uncertain into a single code, Naïve and Uncertain, because both codes could be used to describe the same knowledge states in the current study. Table 2 shows the final categories identified through the analysis.

Table 2: Categories of different knowledge states around AKG

<table>
<thead>
<tr>
<th>Categories</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Knowledge not accessed</td>
<td>Students do not mention a certain knowledge element.</td>
</tr>
<tr>
<td>b) Knowledge not evaluated</td>
<td>Students mention a certain knowledge element (or activate prior knowledge), but no verbal evidence of their self-evaluation of the element is found.</td>
</tr>
<tr>
<td>c) Self-evaluated knowledge</td>
<td>c-1) Sufficient Students mention a certain knowledge element (or activate prior knowledge) and regard the retrieved element as sufficient to solve the problem.</td>
</tr>
<tr>
<td></td>
<td>c-2) Naïve and uncertain Students mention a certain knowledge element (or activate prior knowledge) and regard the retrieved element as naïve or uncertain to solve the problem.</td>
</tr>
<tr>
<td></td>
<td>c-3) Insufficient and unspecified knowledge gaps Students mention a certain knowledge element (or activate prior knowledge) and regard the element as insufficient to solve the problem with an expression of impasse. They do not know the exact point that they are missing.</td>
</tr>
<tr>
<td></td>
<td>c-4) Insufficient and specified knowledge gaps Students mention a certain knowledge element (or activate prior knowledge) and regard the element as insufficient to solve the problem with an expression of impasse. They know the exact point that they are missing.</td>
</tr>
</tbody>
</table>

Findings

The analyses resulted in two main findings. The first finding comprises a quantitative description of the analysis result using the newly developed coding scheme for the participants’ talk-aloud data. The second finding presents examples of the different knowledge states around AKG.

Finding 1: Students spend most of their time solving the problem and seldom evaluate their thoughts.

According to the descriptive analysis of the conversational discourse in the problem-solving phase, over 42% of utterances out of 559 idea units in total belonged to problem assessment. All six peer groups devoted at least more than 30% of talk to assessing the problem. Students seldom engaged in meta-cognitive processes such as recognition of error (utterance count=18), identification of reasons for the error (utterance count=7), or other types of solution evaluation (utterance count=9), although they relatively often faced moments of impasse (utterance
count=64), made assumptions on concepts or processes (utterance count=71), and retrieved prior knowledge (utterance count=41) when solving the given problem. The utterance frequency rate is illustrated in figure 2.

**Figure 2. Utterance frequency rate.**

Abbreviations: PA. problem assessment; O. orientation; IM. impasse; SD. solution development; GA. guess and assumption; PK. prior knowledge; RE. recognition of error; IRE. identification of reasons for the error; SE. solution evaluation without error detection; M. motivation.

**Finding 2: Only a few expressed their experience of knowledge gaps.**

The examples for each knowledge state around AKG are presented in table 3. Six categories were found in total, although only two of these were related to AKG, namely c-3 and c-4. Moreover, there were only two cases of c-3 and c-4, while several cases were found for the other categories (the current paper introduces only one example dialogue for each category due to the word limit).

**Table 3: Example dialogues of different knowledge states around AKG**

<table>
<thead>
<tr>
<th>Categories</th>
<th>Example dialogues</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Knowledge not accessed</td>
<td>N/A</td>
</tr>
<tr>
<td>b) Knowledge not evaluated</td>
<td>Eugene: But since high coefficient of friction means a stronger friction, doesn’t it mean the brake should work faster? That’s how I see it. Grey: Or in my opinion, because it’s heavier, I thought the inertia would be stronger and it might have caused longer time to stop.</td>
</tr>
<tr>
<td>c-1) Sufficient</td>
<td>Grey: When we say this is 25, what’s the reason for dividing it with the weight? Dividing it with the weight suggests, inversely, we used multiples, by multiplying the time the weight can travel, I mean we divided the total distance... right? I think what we did is right.</td>
</tr>
<tr>
<td>c-2) Naïve and uncertain</td>
<td>Jin: Same here. I’m just going by instinct. While going for 2.2 seconds, he braked 15 meters behind, he stopped, so he didn’t cras(h)... he went 15 meters in 2.2 seconds. John: And the force of the 1645kg is 15 meters, then? (Jin: Really?) Yeah, the car went 15m. Because the heavier the weight, the harder the friction. When it’s stronger, right? So I… give up? A different method? … (long pause) Jin: This is 4.5 again? Maybe not, I don’t think this is it, obviously, 559. John: But if we know the speed, ummm Jin: Shouldn’t we look at the car, not the speed?</td>
</tr>
<tr>
<td>c-3) Insufficient and unspecified knowledge gaps</td>
<td>Lucy: Does this 3 second have any significance in the problem? Along with this, so many numbers appear in the latter part of the problem, like the km, 0.6 to 0.7, etc.? Do we have to go all mathematical with these numbers? Jane: Mathematically, but since we don’t know how they’re connected... (long pause) But thinking about it, 3 seconds is a very short time, then can this be an evidence that the driver foresaw this and stopped</td>
</tr>
<tr>
<td>c-4) Insufficient and specified knowledge gaps</td>
<td>Kim: Then, like this. This is a huge difference. Kim: But what bothers me is what we missed... Kim: There may be a way to solve the problem using the coefficient of friction on this road. Right? I feel like this was mentioned for a reason. Seo: Ah... it mentions the weather too... Kim: There’s no reason to slide since it’s a dry road... But because he has history of accident, it’s hard to prove his innocence so we have to present a clear evidence. Seo: Coefficient of friction... apply the coefficient of friction. Then the way is... (long pause) Kim: If I know the formula to use this...</td>
</tr>
</tbody>
</table>

**Discussion**

**General discussion**
The current study comprehensively investigated the conversational discourse during the problem-solving phase in PS-I to identify the cognitive processes that learners undergo when solving a problem and how they reach, or do not reach, the state of AKG. To achieve this goal, this study conducted two separate qualitative analyses. Through deductive content analysis, the authors discovered that during the long period of problem assessment and solution generation, the learners sometimes faced moments of impasse and rarely found errors or reasons for the errors. It seemed that when challenged by impasse moments, learners often made assumptions about information that did not clearly align with their current knowledge. These phenomena required the addition of new categories to the coding scheme used in the previous study on PS-I (Kapur & Kinzer, 2009). The authors assumed that learners are rarely urged to revisit their memory to repair current naïve knowledge (vanLehn, 1999; Chi, 2000) in such challenging explorative problem-solving activities in PS-I. As modifications of the current partial or erroneous schema follow the identification of knowledge gaps, how learners’ knowledge states vary and what makes the AKG state different from others should first be understood to support the PS-I mechanism.

Building on this emergent implication from the first content analysis, this study conducted the second content analysis in an inductive way. Based on the analysis results, this study classified the self-evaluated knowledge states around AKG as shown in Figure 3.

![Figure 3. Classification of self-evaluated knowledge states in terms of gap awareness.](image)

Apparently and naturally, students could not activate any relevant prior knowledge when they had no idea about a concept (i.e., a) knowledge not accessed). When a targeted concept was beyond the students’ level, they kept generating irrelevant remarks. Also, in many cases, even when they activated related concepts, the students still did not perceive the existence of gaps in their ideas because they did not evaluate their knowledge structure of the concept (i.e., b) knowledge not evaluated). Regardless of the possibility that they might have perceived a gap but this was not expressed in the conversation, the context indicated that the students did not reach the state of AKG. It is hard to tell whether the out-of-focus utterances were meaningless for learning, but considering the preparatory effect of the PS-I approach, there needs to be a fence that guides students and prevents them from straying far beyond the track. Even when the students evaluated their thoughts, there were various categories of a perceived knowledge state. Some felt confident about their knowledge and consequently did not experience a gap. Some felt uncertain about their ideas or regarded their ideas as naïve, but they did not notice potential knowledge gaps or show a willingness to dwell on the uncertainties. When the students noticed that their knowledge was insufficient to solve the problem, some specifically located the lacking point, while others just felt that something was missing.

From a comprehensive view, the authors would like to aggregate their findings into the concept of AKG, which has been suggested as a key mechanism for PS-I. While it remains arguable which state in the category can be considered AKG, this study carefully suggests that the ideal AKG state, which previous PS-I research indicated as ‘knowing what you don’t know’, is the last state of knowledge evaluation, namely insufficient and specified knowledge gaps. This is when a student clearly notices the limit of their knowledge and is aware of a learning concept that is needed to solve the problem.

Again, the authors do not conclude that the other states in the category positively (or negatively) affect the efficacy of PS-I. The hypothesis on whether these other states are cases for unproductive failure is contentious and should be closely investigated. In truth, the findings of this study indicate that the students barely reached the insufficient and specified knowledge gaps state, while most of their thoughts remained in other pre-AKG-regarded categories, such as sufficient, naïve and uncertain, and insufficient-unspecified knowledge gaps. This finding is not surprising, given that the learners spent most of their problem-solving time assessing the given problem. Even though some learners agonized over the impasse and tried guessing what they needed to know – which the authors considered as starting points of becoming aware of knowledge gaps – most of them did not go beyond this to evaluate their knowledge in those moments or identify errors and reasons for the errors.

This issue can inform the next research question, namely whether each state in the categories leads to productive PS-I. Would students need to be precisely aware of their gaps in order to integrate knowledge and be...
prepared for the instruction? The authors assume that specific AKG, which learners can experience after agonizing over moments of impasse or explicit or implicit errors (Loibl & Rummel, 2014), would have a better preparatory effect on instruction and bring more beneficial outcomes. The abovementioned study addressed the use of comparing and contrasting activities to specify AKG, however, there still remains room in finding supporting strategies for reaching the AKG state during the problem-solving phase. In this regard, this study suggests classifications, descriptions, and examples of different knowledge states around AKG. This categorization can be utilized as guidance in establishing the directions and boundaries of scaffolding strategies for AKG in future research. Thus, the authors propose follow-up studies that firstly, expand the research scope from the problem-solving phase to the instruction phase to see how different knowledge states around AKG (which is perceived during the problem-solving phase) affect learners’ behaviors during the instruction and learning outcomes, and secondly, explore the effects of instructional interventions promoting AKG.

References


