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Observational investigation of student problem solving: The role and importance of habits

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ABSTRACT: The problem-solving strategies of students enrolled in general chemistry courses have been the subject of numerous research investigations. In most cases, the investigators were interested in the specific areas or concepts that posed the greatest difficulty to a student's success in achieving the correct answer. However, the investigation reported here is based on a study of student problem-solving habits that have been classified by the authors as minor variables: what is the first step that the students complete, how fluent is their work, do they check their work at the end of the process? While these minor variables do not directly evaluate a student's knowledge of chemistry, the results indicate a clear correlation between those students who are "successful" and those students who are "unsuccessful" on a written exam. The data were obtained via observation during think-aloud sessions held in a Midwestern university in the United States of America. The aim of this study is to give educators an understanding of the strategies used by the students as well as provide instructors with visual cues regarding a student's success in problem solving. These problem-solving habits may not directly affect the student's ultimate solution of a single problem, but can indirectly influence their overall performance in either a positive or negative manner.

KEY WORDS: Chemical education, problem solving, undergraduate chemistry, strategies

INTRODUCTION

Success science and engineering fields starts early, in high school or sooner, and is somewhat dependent on early interest in the world and its workings (Kokkelenberg & Sinha, 2010; Taber, 2010). Successful STEM (science, technology, engineering, and mathematics) students should be able to account for the changes observed in natural phenomena, advance the understanding of how nature works, and solve the multitude of problems faced in the modern world (Leonard, Gerace, & Dufresne, 1999). Of course, success must be fostered at all levels, and the problem solving abilities of college undergraduates must be nurtured (Overton & Potter, 2011).

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In order to facilitate student's and teacher's efforts to achieve these goals, researchers have completed numerous studies which assist in the identification of the nature of challenges encountered in learning and teaching science as well as exploring the problem solving process (Cavas, 2010; Stamovlasis & Tsaparlis, 2000; Sutherland, 2002; Teodorescu et al., 2008; Uzuntiryaki, 2007). Students' success in problem solving is influenced by several factors including their knowledge structures (Bédard & Chi, 1992), conceptual understanding of subject matter (Phelps, 1996), teacher assessment methods (Chittleborough, Treagust, & Mocerino, 2005), reasoning ability (Bird, 2010; Chandran, Treagust, & Tobin, 1987; Kwon, Lawson, Chung, & Kim, 2000), cognitive development (Atwater & Alick, 1990; Huitt & Hummel, 2003; Pandey, Bhattacharya, & Rai, 1993), and working memory capacity (Overton & Potter, 2011; Stamovlasis & Tsaparlis, 2000; Tsaparlis, 1998). Education researchers have investigated these factors in numerous research investigations.

It has also been observed that students start first year college chemistry with a high self-concept (self-confidence), but frequently lose that confidence during their first general chemistry course (Bowman, 2012). A student's confidence in their ability to do chemistry is an essential component of success (Ajzen, 2002; Bauer, 2005); however, the challenge is not always associated with the students' motivational level, cognitive abilities, or understanding of chemical concepts. While some students have the basic knowledge of chemistry and mathematics, a good set of problem-solving abilities, and relatively high confidence in their ability to learn chemistry and solve problems, they still cannot successfully apply their skills and knowledge to accurately complete a set of problems (Gulacar & Fynewever, 2010).

In previous research, Gulacar and Fynewever (2010) observed additional variables that were believed to be indirectly affecting student's success in problem solving and, as a result, preventing them from obtaining the correct solutions. While these variables, not previously reported, may not have been as critical as the cognitive variables or knowledge structures, these variables may hinder students' problem-solving performances. For example, when students relied purely on a trial-and-error method (means-ends analysis) and adapted an algorithmic thinking style, they could not analyze the given information effectively and put the necessary components together to obtain the correct answer.

In this study, a series of minor, often ignored, problem-solving habits which expanded the understanding of differences between successful and unsuccessful students was investigated. When considering these variables along with the major variables investigated and cited in previous investigations (Arasasingham, Taagepera, Potter, & Lonjers, 2004; Gulacar & Fynewever, 2010; Overton & Potter, 2011), a more complete representation about the challenges that students face with problem-solving is obtained and more effective methods can be developed to improve students' abilities to become more successful problem-solvers in the sciences.

Problem solving and characteristics of problem solvers

Before examining the details of the problem solving procedure, clarification of the definitions of common terms used in this paper is necessary. One might suppose the intended meaning of words can be transferred from author to the reader without difficulty, yet often the ambiguity of the words prevents this transfer (Crago, Eriks-Brophy, Pesco, & McAlpine, 1997). For the purposes of this study, Hayes' (1981, p. 1) definition of problem solving was used:

> "Whenever there is a gap between where you are now and where you want to be, and you do not know how to find a way to cross that gap, you have a problem and the problem solving is what you do, when you do not know what to do."

This definition makes a distinction between two common tasks assigned and encountered in the everyday and academic lives of students: problems and exercises (G. M. Bodner, 1991). Although both these tasks involve a gap in knowledge, exercises require a student to use a method that is known to the solver, while problem solving does not.

Despite the fact that a problem solver is unsure how to cross the gap and reach a successful solution at the outset, there are still some strategies which are viewed as more effective than others and could facilitate the solver's efforts. Studies report that successful students prefer and adapt such methods more than unsuccessful students, which can cause some differences in problem solving achievements and performances (Shadle, Brown, Towns, & Warner, 2012). A detailed examination of successful and unsuccessful students' problem-solving performances illuminates the nature of those differences and shows how they relate to utilized strategies (working-forward and means-ends analysis) as well as adapted approaches (conceptual vs. algorithmic) in problem solving (Heyworth, 1999).

Unsuccessful students cannot make connections easily between what they have learned and the information provided in the questions, especially when students are unfamiliar with the type of the questions. Therefore, they tend to use more means-ends analysis methods and take an algorithmic approach, looking for equations that serve their purpose rather than trying to understand the questions conceptually or examining the underlying principle in the question (Heyworth, 1999). In other words, unsuccessful students jump right into a problem without thinking about all of the aspects of the problem. As a result, more errors are obtained while performing the calculations.

On the contrary, successful students are careful and make fewer mistakes while carrying out the solution. Unlike their unsuccessful counterparts, they think ahead, devise strategies, and modify those strategies as needed (G. Bodner & Domin, 1995) in a working-forward method. Successful students are more able to link concepts with their context and with the real world (King & Ritchie, 2013). Moreover, they seem to have a wider and deeper knowledge base, can make more relevant connections to the real world, and usually have better justifications for their answers (Noroozi, Biemans, Busstra, Mulder, & Chizari, 2011).

METHODOLOGY

Research question

The data was obtained from a study involving 17 undergraduate science majors registered in second semester general chemistry at a medium-sized university in the United States of America. The aim was to identify differences between successful and unsuccessful students in their performances, skills, and achievement levels by analyzing their behaviors and performance using a series of stoichiometry questions varying from simple exercises to challenging problems. Evaluating both the major factors influencing problem-solving performance as well as the minor variables, discussed here, enables the detection of different patterns among student's problem-solving strategies and helps provide a holistic account for the difficulties that students face while solving problems.

The principle question for this study was: "Are there any significant differences between the problem solving habits of successful students and those of unsuccessful students?" During the course of the investigation, the students' habits related to starting a problem, finishing a problem, their overall cognitive approach to a solution, and their solution method were examined.

Participants

Ultimately, the goal of the research project was to identify the characteristics of undergraduate students that are related to "successful" or "unsuccessful" performance. Identification of the characteristics should assist in the development of teaching methodologies which will assist in improving the overall fraction of the students who not only complete the general chemistry curriculum, but who are high achievers in all academic areas, as the characteristics that are developed early in the academic career of the students often translates to subsequent courses.

After getting the instructor's consent, invitations were distributed to students taking General Chemistry II. All volunteers who were all declared science majors though not chemistry majors, were identified and given a diagnostic test, created by the first author and an additional three chemistry professors and titled the Chemistry Achievement Test (CAT). The CAT is composed of 15 stoichiometry questions. The test appeared to do a good job in identifying the desired participant groups evidenced by a high correlation ($r = 0.84$, $p < 0.01$) with the graded work of students from the think-aloud protocols (see below). The scores obtained by the students on the CAT were ranked: students who scored 67% or above were categorized as "successful" and students who scored 47% or below were categorized as "unsuccessful." Students who scored between 47% and 67% were excluded from consideration in the study. In the group of students, nine students were classified as successful and nine students were classified as unsuccessful; one of the students in the unsuccessful group was removed from the study after the first think aloud protocol due to scheduling conflicts and was not included in the final analyses.

Topic for the study: Stoichiometry

Stoichiometry has been cited as one of the most challenging topics in the general chemistry curriculum (Felder, 1990; Wolfer & Lederman, 2000) and has been described as the "heart" of first-year chemistry. An excellent understanding of the stoichiometric concepts introduced in general chemistry is vital and requires academic skills, practice in solving chemistry-related problems, organized knowledge of chemistry concepts, and a knowledge of mathematics. With the goal of understanding the characteristics of successful and unsuccessful students, a set of questions was selected that ranged from simple chemistry exercises to difficult limiting reactant problems, for a total of thirteen easy questions and twelve more complex, difficult questions, a total of 25 questions.

Think-Aloud Protocols

Think-aloud protocols were used to collect both quantitative and qualitative data on students' habits and skills in solving stoichiometry problems. The protocols were scheduled on four separate days, during which the student was expected to solve all 25 questions. Each session was one-hour in length. Two months were required to collect all of the data. The number of questions solved in any one particular session varied from student to student, but all of the students were able to complete the questions within four sessions. The questions were not presented in order of increasing difficulty to avoid implicit instruction.

During the sessions, students were instructed and encouraged by the first author to solve the questions while verbalizing their thoughts (Heyworth, 1999; Nakhleh & Mitchell, 1993; Potvin, 2005). All of the sessions were recorded using digital voice recorder and digital cameras. Audio recordings were later transcribed for analysis. Following the completion of all sessions, the solutions were graded and analyzed using quantitative and qualitative methods (Gulacar & Fynewever, 2010).

The study utilized both quantitative and qualitative methods since a mixed method approach has several advantages, including the ability to check the reliability of the data through different instruments and to clarify findings from one method with the use of another method (Greene, Caracelli, & Graham, 1989). The student's solutions to the 25 questions in the think-aloud protocol constituted the quantitative part of the study and observations and recordings from the think-aloud protocols constituted the qualitative component of the design. Within the current study, data collected from think-aloud protocols were used to determine what differences, if any, existed between successful and unsuccessful students. SPSS 20 was used to calculate the *t*-tests and χ^2 analyses utilized in this paper.

Observed variables

The variables that were evaluated are described in detail below and include: first tried to understand, not hesitant, working forward, problem-solving approach, and last action.

First tried to understand: For each student, the number of questions on which they wrote information down immediately was totaled, and the number of questions that they struggled to understand before they began was totaled. The variable measured was the number of times they first struggled divided by the total number of questions (25).

Not hesitant (fluent): In order to evaluate students' subsequent behavior, their actions were analyzed after the initial step. It was noted whether the student paused for a while, either doing nothing or rereading the question or if they continued on with the solution without hesitation. If the student paused, "hesitant" was assigned; if the student continued working, "not hesitant (fluent)" was assigned. The variable measured was the number of times "not hesitant" was assigned divided by the total number of questions (25).

Working forward (WF): The students' strategies were identified as the working forward method (WF) when they appeared to know what the question was about and identified a method to solve the problem at the beginning of the question. On the other hand, students' strategies were identified as a means-ends (ME) analysis when they did not appear to know how to proceed in the problem-solving process or the goal of the question. The variable measured was the number of times a student used a WF method on a question divided by the total number of questions (25).

Problem solving approach: The work of the students on each question was broadly classified as conceptual thinking (i.e., thinking mostly about the concepts behind the question), algorithmic thinking (i.e., thinking mostly about the calculations needed to solve a question), or a combination of the two methods (i.e., mixed).

Last action: Whether or not a student checked their answer after completing the problem was recorded for this variable. The students either did not check their answers, checked that their calculations were done correctly, or checked that the answer made sense conceptually. Checking calculations was only applied if the student checked to make sure they had done the calculations correctly. If a student was considering the math while seeing if the answer made sense, it was considered checking conceptually.

RESULTS AND DISCUSSIONS

Observations of the students when starting problems

When a student first reads a problem, two major approaches were observed: students either take a moment to analyze the problem or they immediately start writing down information. If a student understands the question being asked, it is quite possible that they understand the problem completely and do not need additional time to analyze the question in greater detail. As a result, they can immediately start writing out the solution to the problem. However, students who do not understand the problem may also start out by writing instead of thinking out a solution, writing down information that they believe to be related to the question without completely considering the question. These students may be focused on details such as memorized mathematical equations rather than the appropriate means of solving the problem. As a result, immediately writing information down may not indicate whether a student will successfully complete the question.

As seen in Table 1, no statistically significant difference ($p = 0.396$) was observed between the successful and the unsuccessful students when comparing how often a student began a problem by writing or by thinking. Though the difference was not significant, it was interesting to note that the unsuccessful students began by writing about half of the time, while successful students began by writing 55% of the time. It is possible that a larger sample may have found a significant difference between the two groups. This finding was surprising. It was assumed that successful students would prefer a more conceptual, evaluative method of starting the question, consistent with the literature (Chi, Feltovich, & Glaser, 1981; Schneider, Rittle-Johnson, & Star, 2011), and thus would begin more problems by trying to understand, rather than immediately writing. Additionally, it is not necessarily evident from the initial observations whether a student who began by immediately writing had analyzed the question, as opposed to someone who just started writing without appropriate analysis. As a result, it was clear that the subsequent behavior of each student was more likely related to the ultimate success of a student on a specific problem.

In order to evaluate their subsequent behavior, the observations of students' activities after the initial step were analyzed. The first author noted whether a student paused for a while (e.g. doing nothing or rereading the question), or whether the student continued on with the solution without hesitation (hesitant/fluent; *see above*) while administering the think-aloud protocols. The investigation of whether a student hesitated after the first step exhibited a statistically significant ($t(15) = 3.016$, $p < .05$) difference between the fluencies of unsuccessful and successful students. Successful students (S) exhibited significantly less hesitancy than the unsuccessful students (U). Unlike their initial actions on a problem, their continued actions did differentiate the successful students from the unsuccessful students. This most likely indicates that the successful students were more familiar and comfortable with the material than were their unsuccessful counterparts.

As seen above, whether a student was successful or unsuccessful was not an indicator of whether or not they would write down some information prior to thinking through a problem. When writing down information initially, students may be doing so because they understand how to proceed and are organizing their information, or because they have no idea what to do and are fumbling for a path forward (or some combination of the two, depending on the situation). Instead, whether a student was hesitant or fluent with a problem was a significant difference between successful and unsuccessful students.

Indeed, it seems that familiarity with a problem, or some aspect of the problem, may be what is differentiating students in this case. Since students were classified based on whether they had a high or low chemistry aptitude (as measured by the CAT), it follows that the successful students (higher aptitude) were more familiar with the problems and hesitated less. Problem solving has been called "knowing what to do when you don't know what to do" (Frank, Baker, & Herron, 1987), and students with higher chemistry aptitudes would be more able to piece together the disparate parts of the problem in order to create a solution than students who were not fluent in chemistry. Helping students create bridges between those knowledge pieces may help them improve their problem-solving abilities.

Table 1: Comparisons of successful (S) and unsuccessful (U) students in problem solving procedures. Means shown are the percentage of problems on which students exhibited the given factor. Significant results are in bold; non-significant results are in italics.

	t-test for Equality of Means			Levene's Test for Equality of Variances		Means	
	t	df	Sig.	F	Sig.	S	U
First Tried to Understand	-.874	15	.396	1.196	.291	46%	50%
Not Hesitant (fluent)	3.016	10.4	.012	4.998	.041	37%	19%
Working Forward (WF)	4.144	15	.001	.395	.539	66%	39%

As George M. Bodner (1987) stressed in his definition of problem solving, there exists an elusive interaction between the task and the individual solving it. For successful students, some of the problems were more like simple exercises whose solutions were known and understood from the beginning (they were "fluent" in the problem), whereas for the unsuccessful students, more of the problems were difficult to comprehend and created a barrier to ultimate success. This observation is consistent with the fact that people at a higher level of understanding are able to quickly analyze and initiate the problem-solving sequence, particularly with questions that have some degree of familiarity, than those people that are at a lower level of understanding.

Observations of the student's approach to problem-solving

To further analyze differences in how students approached problem solving, each student's approach was classified, as was the method they used to solve the problem. The various approaches can be seen in Table 2, while the method (i.e., working forward or means-ends) preference is shown in Table 1.

When transcripts of the sessions indicated that the students were solving the question in a manner unrelated to the relevant chemistry concepts simply to get an answer, the approach was considered algorithmic. In contrast, a student's approach was classified as conceptual if they were solving the problems in a manner that was more mindful of the conceptual context. These students appeared to know what they were looking for and understood the relationship between the questions and the concepts that they had learned rather than simply answering a question or solving a problem to obtain a number or a unit. The students were aware of the connections and obtained answers that conceptually made sense to them.

As can be seen in Table 2, neither the successful nor the unsuccessful students approached each problem in exactly the same manner. Each used some conceptual approaches, some algorithmic approaches, and some mixed approaches. However, a χ^2 analysis showed that there were significant differences ($\chi^2(2) = 39.657$, $p < .001$) between the successful and unsuccessful students and their approaches. Successful students were far more likely to use a conceptual approach to a problem (57% of the time) and rarely used an algorithmic-only approach (2%). In contrast, the unsuccessful students spent roughly equal time in purely conceptual or algorithmic approaches (about 20% each), with the majority of their approaches being mixed. As expected, an approach that relies on the underlying concepts was associated with the more successful students.

Table 2: Overall student approaches to problem solving

			Approach‡	
		Conceptual	Algorithmic	Mixed
Successful	Count	57%	2%	41%
	Expected*	37.3	10.9	51.7
Unsuccessful	Count	18%	20%	63%
	Expected*	37.7	11.1	52.3

*Expected count calculated by SPSS
‡$\chi 2(2) = 39.657$, $p < .001$

In the same manner, two common methods employed by students were defined: the working forward (WF) method or a means-ends (ME) method. Students' strategies were identified as a working forward method when they appeared to know what the question was about and had identified a method to solve the problem at the beginning of the question. The working forward method is typically attributed to experts (Heyworth, 1999). These students appeared to be completing an exercise that was straightforward for them, rather than a challenging problem which demanded more analysis. On the other hand, the students' strategies were identified as the means-ends method when they did not appear to know the goal of the problem or how to proceed in the problem-solving process. These students appeared to be focusing on unknowns and not analyzing the specific situation described in the question. The students were trying to apply strategies which had worked for them before to obtain the answer, without realizing that the question could not be solved in a memorized or algorithmic manner. As with the problem approaches above, a student's method was analyzed for each question (i.e., twenty-one times per student).

As can be seen in Table 1, successful students used a WF method 66% of the time while unsuccessful students used as WF method less than 40% of the time, a significant difference ($t(15) = 4.144$, $p < .01$). These percentages were somewhat close to those seen in Table 2, which suggested a strong correlation between students using a WF method and a conceptual approach. Pearson's correlation, r, was calculated between the percent of problems for which each student used a working forward method and the number of times they used a conceptual approach. There was a very strong, significant correlation between the two variables: $r(17) = .929$, $p < .001$. It can be seen that a working forward method and a conceptual approach are linked, and it is likely that one relies on the other for success.

Although, while solving the problems, successful students sometimes saw their task as getting a number or finding an answer with the unit they thought as the right one, unsuccessful students appeared, in observation, to be more algorithmic thinkers. The χ^2 results also supported this finding and revealed that successful students approached the problems in a conceptual manner significantly more often than did unsuccessful students. In parallel with students' overall approach on problem solving, students tended to use the means-ends method when they solved the problems and did not really know what they needed to do. On the other hand, students preferred to use a working forward method when they solved the problems conceptually and knew what they need to do.

Observations of the students checking the final answer

In the same manner that student differences in starting to solve a problem were evaluated, how students completed the problems was also observed; whether or not a student checked the problem was the variable of measure. Once again, no absolute behavior could be determined as students did not perform the same exact final actions on each problem. Table 3 depicts the number of times that the students checked their answers with regards to the conceptual nature of the problems and also with regards to the mathematical nature of the problems. It is important to note that, if a student checked the conceptual correctness of their answer, the math was checked as part of the review; "checked math" was only assigned if the students did not consider whether or not the answer made sense, but rather just checked that they had performed the mathematical function correctly.

While none of the students checked their answers more than half of the time, there was significant variation between students who checked their answers, both conceptually and numerically, and those that did not ($t(15) = 3.740$, $p < .01$). Successful students did check their answers more frequently (20% of the time) than did unsuccessful students (7% of the time). However, students characterized as "successful" appeared to be significantly more likely to check the conceptual nature of the answer than the students characterized as "unsuccessful". This was determined to be statistically significant at the 95% level ($\chi^2(2) = 6.566$).

Additionally, the manner by which students finished was affected by the context of the questions. If the students had a good understanding of the concepts involved in the questions and were familiar with the context of the question, as was observed in the mathematical questions, the students almost always checked their answers. In contrast, if the students had a poor conceptual knowledge, they either preferred not to check the answers at all or checked the answers in terms of the algorithm used, rather than ensuring that the answer was logical.

Table 3: Frequency of whether or not a student checked their answer when finished with a problem

		Last Action‡		
		Checked Concept†	Checked Math	Did Not Check
Successful	Count	13%	7%	79%
	Expected*	8.5	5.5	85.1
Unsuccessful	Count	4%	4%	92%
	Expected*	8.5	5.5	85.9

*Expected count calculated by SPSS
†Checked for conceptual accuracy
‡$\chi 2(2) = 6.566$, $p < .05$

A clear distinction was observed between the students classified as unsuccessful and the students classified as successful in their preference for checking answers, particularly when checking the conceptual nature of the answer. The successful students were more likely to catch minor mistakes, such as mathematical or transcription errors. Catching the errors often led to the correct answer since they had a better understanding of the context of the questions. In contrast, the unsuccessful students had limited understanding of the nature of the questions and were unable to check their solutions as they progressed through the problem. This is likely because they were unfamiliar with the material and the complexity of the questions taxed the students' working memory capacities which prevented the students from thinking about the details and detecting errors.

CONCLUSIONS

Overall, there were no significant differences between successful and unsuccessful students when beginning a problem. Neither was more likely to begin by contemplating the problem or by writing information down. However once begun, successful students were less likely to hesitate while working through the problem. This was likely due to a higher level of comfort with the concepts or the math behind the problems. Of course, while a measured difference does not imply a causal relationship, it is unlikely that instructing students not to hesitate while working problems will make them more proficient. Rather, the lack of hesitation is a result of better understanding.

When finishing problems, successful students were roughly twice as likely as unsuccessful students to check their answers before moving on. While the difference was significant, the overall numbers showed that most students failed to check their answers most of the time. Successful students were more likely, however, to check for conceptual accuracy than unsuccessful students, which does appear to agree with the above observation that successful students were more comfortable with the problems. It was observed that students tended to check answers on problems for which they were more comfortable; conceptual accuracy was only checked when a student had some confidence in their conceptual understanding.

Successful students were also observed to approach problems in a conceptual manner more often than unsuccessful students. There was also a strong correlation between the number of times a student approached a problem conceptually and the number of times their method was a working forward (WF) method, a method usually associated with experts. Combining these observations, it appears that if a student was approaching a problem algorithmically, the student probably did not anticipate a reasonable pathway to the solution and was solving the problem just for the sake of finding a number or a unit. The student who approached a problem conceptually, however, knew what they were doing and understood the relationship between the calculations and the overall problem. These students, then, were able to use a WF method because they had an overall understanding. This method was used when the solution of the question was more or less known by the students. This is not to say that the students knew the whole solution at the beginning, but that they knew what to expect from the solution of the problem. Students using a working forward method looked at the givens in the problem and then moved from the statement of the problem to a physical representation of it and finally to an answer.

Suggestions on improving students' problem solving abilities

Within the classroom environment, it is difficult to monitor and interpret the habits of each individual student; however, educators can certainly use the results of the study to impact the methods that they use to deliver the information to the students in the classroom and also in more individualized settings. Educators not only provide content information, but serve as role models to the students in the problem-solving process. As noted earlier, experts in the field utilize the working forward model, exhibit little hesitancy, and solve the problem successfully.

While working with the students, educators should emphasize the key aspects of the problem, whether that is the terminology, the values provided, or the like, that directed them in the problem-solving process. The students need to recognize and understand the visual cues that enable the solution of a problem that make the problem unique and also how to use similar visual cues in the solution of a future problem. Educators should model checking the answer, both conceptually and mathematically, as this is a skill that appears to be lacking in many entering freshman chemistry students, regardless of their success within the classroom environment.

Within smaller environments, such as recitation sections or office hours, individualized attention can be given to the student, and recommendations regarding the problem-solving process can be implemented with dramatic impact on the individual student. Simply asking the student to read the problem and perform a short think aloud protocol can assist the educator in understanding the misconceptions that arise from the lecture material in the minds of the students, not only helping the student at the moment, but also assisting in the continual improvement of the lecture environment.

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REFERENCES

Ajzen, I. (2002). Perceived Behavioral Control, Self-Efficacy, Locus of Control, and the Theory of Planned Behavior. *Journal of Applied Social Psychology, 32*(4), 665-683.

Arasasingham, R. D., Taagepera, M., Potter, F., & Lonjers, S. (2004). Using knowledge space theory to assess student understanding of stoichiometry. *Journal of Chemical Education, 81*(10), 1517-1523.

Atwater, M. M., & Alick, B. (1990). Cognitive development and problem solving of Afro-American students in chemistry. *Journal of Research in Science Teaching, 27*(2), 157-172.

Bauer, C. F. (2005). Beyond "Student Attitudes": Chemistry Self-Concept Inventory for Assessment of the Affective Component of Student Learning. *Journal of Chemical Education, 82*(12), 1864-1870.

Bédard, J., & Chi, M. T. H. (1992). Expertise. *Current Directions in Psychological Science, 1*(4), 135-139.

Bird, L. (2010). Logical Reasoning Ability and Student Performance in General Chemistry. *Journal of Chemical Education, 87*(5), 541-546.

Bodner, G., & Domin, D. (1995). The role of representations in problem solving in chemistry. In D. R. Lavoie (Ed.), *Toward a Cognitive-Science Perspective for Scientific Problem Solving. NARST Monograph, Number Six* (Vol. 6, pp. 245-263). Columbus, OH: NARST.

Bodner, G. M. (1987). The Role of Algorithms in Teaching Problem Solving. *Journal of Chemical Education, 64*(6), 513-514.

Bodner, G. M. (1991). Toward a unified theory of problem solving: A view from chemistry. In M. U. Smith (Ed.), *Toward a unified theory of problem solving: Views from the content domain* (pp. 21-34). Hillsdale: Lawrence Erlbaum.

Bowman, C. R. (2012). *Relationship Between Study Habits and Student Attitudes Towards Science and Technology.* (Ph.D. Doctoral Dissertation), Drexel University. Retrieved from http://hdl.handle.net/1860/3836

Cavas, B. (2010). A Study on Pre-Service Science, Class and Mathematics Teachers' Learning Styles in Turkey. *Science Education International, 21*(1), 47-61.

Chandran, S., Treagust, D. F., & Tobin, K. G. (1987). The role of cognitive factors in chemistry achievement. *Journal of Research in Science Teaching, 24*, 145-160.

Chi, M. T. H., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science, 5*(2), 121-152.

Chittleborough, G., Treagust, D., & Mocerino, M. (2005). Non-major Chemistry Students' Learning Strategies: Explaning Their Choice and Examining the Implications for Teaching and Learning. *Science Education International, 16*(1), 5-21.

Crago, M. B., Eriks-Brophy, A. A., Pesco, D., & McAlpine, L. (1997). Culturally Based Miscommunication in Classroom Interaction. *Language, Speech, and Hearing Services in Schools, 28*(3), 245-254.

Felder, R. M. (1990). Stoichiometry without tears. *Chemical Engineering Education, 24*(4), 188-196.

Frank, D. V., Baker, C. A., & Herron, J. D. (1987). Should students always use algorithms to solve problems? *Journal of Chemical Education, 64*(6), 514.

Greene, J. C., Caracelli, V. J., & Graham, W. F. (1989). Toward a Conceptual Framework for Mixed-Method Evaluation Designs. *Educational Evaluation and Policy Analysis, 11*(3), 255-274.

Gulacar, O., & Fynewever, H. (2010). A Research Methodology for Studying What Makes Some Problems Difficult to Solve. *International Journal of Science Education, 32*(16), 2167-2184.

Hayes, J. (1981). *The Complete Problem Solver*. Philadelphia, PA: The Franklin Institute Press.

Heyworth, R. M. (1999). Procedural and conceptual knowledge of expert and novice students for the solving of a basic problem in chemistry. *International Journal of Science Education, 21*(2), 195-211.

Huitt, W., & Hummel, J. (2003). Piaget's theory of cognitive development. *Educational Psychology Interactive*. http://www.edpsycinteractive.org/topics/cognition/piaget.html

King, D. T., & Ritchie, S. M. (2013). Academic Success in Context-Based Chemistry: Demonstrating fluid transitions between concepts and context. *International Journal of Science Education, 35*(7), 1159-1182.

Kokkelenberg, E. C., & Sinha, E. (2010). Who succeeds in STEM studies? An analysis of Binghamton University undergraduate students. *Economics of Education Review, 29*(6), 935-946.

Kwon, Y.-J., Lawson, A. E., Chung, W.-H., & Kim, Y.-S. (2000). Effect on Development of Proportional Reasoning Skill of Physical Experience and Cognitive Abilities Associated with Prefrontal Lobe Activity. *Journal of Research in Science Teaching, 37*(10), 1171-1182.

Leonard, W. J., Gerace, W. J., & Dufresne, R. J. (1999). Concept-Based Problem Solving: Making Concepts the Language of Physics. Technical Report. http://www.eric.ed.gov/ERICWebPortal/detail?accno=ED468197

Nakhleh, M. B., & Mitchell, R. C. (1993). Concept learning versus problem solving: There is a difference. *Journal of Chemical Education, 70*(3), 190-192.

Noroozi, O., Biemans, H. J. A., Busstra, M. C., Mulder, M., & Chizari, M. (2011). Differences in learning processes between successful and less successful students in computer-supported collaborative learning in the field of human nutrition and health. *Computers in Human Behavior, 27*(1), 309-318.

Overton, T. L., & Potter, N. M. (2011). Investigating students' success in solving and attitudes towards context-rich open-ended problems in chemistry. *Chemistry Education Research and Practice, 12*(3), 294-302.

Pandey, N. N., Bhattacharya, S. B., & Rai, V. K. (1993). Longeot test of cognitive development in Indian context. *Studies in Educational Evaluation, 19*(4), 425-430.

Phelps, A. J. (1996). Teaching to Enhance Problem Solving: It's More than the Numbers. *Journal of Chemical Education, 73*(4), 301-304.

Potvin, P. (2005, April 3-8). *The use of explicitation interview in the study of [non-] scientific conceptions.* Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Dallas, TX.

Schneider, M., Rittle-Johnson, B., & Star, J. R. (2011). Relations among conceptual knowledge, procedural knowledge, and procedural flexibility in two samples differing in prior knowledge. *Developmental Psychology, 47*(6), 1525-1538.

Shadle, S. E., Brown, E. C., Towns, M. H., & Warner, D. L. (2012). A Rubric for Assessing Students' Experimental Problem-Solving Ability. *Journal of Chemical Education, 89*(3), 319-325.

Stamovlasis, D., & Tsaparlis, G. (2000). Non-linear analysis of the effect of working memory capacity on organic-synthesis problem solving. *Chemistry Education Research and Practice, 1*(3), 375-380.

Sutherland, L. (2002). Developing Problem-Solving Expertise: The Impact of Instruction in a Question Analysis Strategy. *Learning and Instruction, 12*(2), 155-187.

Taber, K. S. (2010). Challenging gifted learners: general principles for science educators; and exemplification in the context of teaching chemistry. *Science Education International, 21*(1), 5-30.

Teodorescu, R., Bennhold, C., Feldman, G., Henderson, C., Sabella, M., & Hsu, L. (2008). Enhancing Cognitive Development through Physics Problem Solving: A Taxonomy of Introductory Physics Problems. *AIP Conference Proceedings, 1064*(1), 203-206.

Tsaparlis, G. (1998). Dimensional analysis and predictive models in problem solving. *International Journal of Science Education, 20*, 335-350.

Uzuntiryaki, E. (2007). Learning Styles and High School Students' Chemistry Archievement. *Science Education International, 18*(1), 25-37.

Wolfer, A. J., & Lederman, N. G. (2000). Introductory College Chemistry Students' Understanding of Stoichiometry: Connections between Conceptual and Computational Understandings and Instruction. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, New Orleans, LA. http://www.eric.ed.gov/ERICWebPortal/detail?accno=ED440856