Research on Geoscience Students' Self-Regulated Learning, Metacognition, and Affect

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Introduction

When we think of learning, we commonly focus on the content. However, it is how individuals navigate that content through their affect (emotional response, attitudes, beliefs), their ability to self-regulate (which includes one's motivations and interests) and their metacognitive capabilities (ability to reflect on what they know, what they don't know and what they need to do to improve on those weaknesses) that ultimately determines whether and how they interact with the content. While research clearly indicates that the ability to self-regulate is critical for success in learning in general (Figure 1; for example, Pintrich & Zusho, 2007; Zimmerman, 2001; Schraw, 1998), we are still trying to determine what this looks like for the geosciences. In addition, while there is initial evidence that the same motivational and affective factors that impact student learning in general also apply to learning in geoscience contexts (Lukes & McConnell, 2014), much more needs to be explored. We still need to learn how self-regulation, metacognition, and affect can enhance (or inhibit) one's ability to navigate content necessary for specific skill sets within the geosciences (e.g., spatial reasoning). Findings might be different for various populations and in a range of contexts, and research in the geosciences needs to investigate these variations. We also need to better determine how we can support faculty in facilitating student development of these skills and capabilities.

Figure 1. This image represents the value that metacognitive capabilities have in student learning. When students hone the ability to be self-regulated learners they take greater control over their actions as they strive toward academic acheivement goals and development of transferable skills.

Many of the questions researchers in the fields of education psychology, cognitive science, and science education still have about matters of self-regulated learning, metacognition, and affect are in direct alignment with the interests of GER. Some of these emergent lines of inquiry in these other fields can inform GER through the use of more-established theories and methodologies. The geosciences may be a unique context in which these questions can be investigated and the findings generated from GER researchers may be of interest to the broader learning science audience which, in turn, may provide GERs new dissemination outlets and interested audiences to publish and communicate their research findings.

Below, we articulate four Grand Challenges that highlight needed areas of research on self-regulated learning, metacognition and affect. These are organized around important ways in which these factors emerge in teaching and learning: in the development of student skills, in the support of a diverse population of learners, in the support of educators teaching these students, and in assuring that research on these factors is of the highest standards.

Grand Challenges

Grand Challenge 1: Student Skills: How do we support students in developing their ability to learn, regulate, and apply the skills and ways of thinking in the geosciences along the novice to expert continuum?
Supporting student **s**uccess and preparing students for careers and social/civic involvement after college is an important aspect of the undergraduate teaching and learning experience. Integrating skill development beyond academic and technical skills, to include metacognition and self-regulation, is important in developing life long learners and expertise.

Grand Challenge 2: Inclusion: What are effective strategies in engaging a diverse population of students in their learning and sustaining their interest in the geosciences?
The geosciences have been known for having low numbers of underrepresented students participate and major in the field. In order to increase underrepresentation in the geosciences, and to assure success for all students, we must determine what strategies are most effective in engaging students and to effectively learn geoscience content.

Grand Challenge 3: Assessment: How can we measure student experiences in the geosciences through the lens of self-regulation, motivation and other components using the most cutting edge research technology and methodologies?
The GER field should utilize established assessment methods, tools, and instruments and build on the approaches that other disciplines (e.g., science education, psychology, learning sciences, etc.) have developed. Researchers should apply these methods and approaches to the specific learning needs of students within the variety of geoscience learning settings and contexts.

Grand Challenge 4: Educators: How support the geoscience community in learning and implementing classroom strategies that are known to be effective in supporting students affect, metacognition and self-regulation of learning?
Faculty guidance is vital for coaching students to be self-regulated learners. In order for Challenges 1 and 2 to be implemented broadly and successfully, instructors must be knowledgeable and comfortable using classroom strategies related to affect, metacognition, and self-regulation of learning.

Grand Challenge 1:

Student Skills: How do we support students in developing their ability to learn, self-regulate, and apply the skills and ways of thinking in the geosciences along the novice to expert continuum?

Rationale

Part of preparing students for careers and social/civic involvement after college, as well as contributing to students' academic success, is helping them acquire and hone skills beyond domain knowledge and technical skills. Students need adequate "soft skills" that help them succeed when working in teams, communicating information, and managing their own time and effort. Acquisition of such transferable learning skills is critical in helping students advance along the novice-expert continuum. Individually, these learning skills have been shown to be malleable, such as students' ability to self-regulate their learning (Schraw et al., 2006), effectively monitor their metacognitive processes (e.g., Nietfeld, Cao, & Osborne, 2006), and improve aspects of their affective responses to learning science (such as task value, e.g., Zapeda et al., 2015).

Direct instruction of learning strategies has been suggested as the most effective means of improving these student variables for science learning (e.g., Zapeda et al., 2015). Additionally, prior work has suggested that within the sciences, there is domain (i.e., discipline) specificity in the efficacy of certain self-regulated learning behaviors that warrant further investigation (Schraw, Crippen, & Hartley, 2006; Greene et al., 2015). While efforts have been made to characterize student abilities in other domain-specific applications via inquiry specifically related to student approaches to chemistry learning (e.g., Pintrich & Zusho, 2003, Zuscho, Pintrich, & Coppola, 2003), biology learning (e.g., Stanton et al., 2015), and physics learning (e.g., Zapeda et al., 2015), little focused work has been conducted to characterize and improve instruction of many of these skills as applied to the learning of the geosciences. This is not to say, however, that no attention has been paid to any of these endeavors. The construct of the affective domain in the geosciences has been elucidated (van der Hoeven Kraft, 2011) and reviewed (McConnell & van der Hoeven Kraft, 2011) in recent work. Future work should seek to similarly investigate students' approaches to the self-regulatory behaviors and metacognitive processes associated with geoscience learning. In addition, acquisition of such transferable skills is critical in helping students advance along the novice-expert continuum (Petcovic & Libarkin, 2007).

In addition, within education psychology, learning skills represent a separate but related construct seeking to understand how students can share their regulatory behaviors via a "Socially-Shared Regulation of Learning" (SSRL; Panadero & Järvelä, 2015 for a review), which can be described as a social-constructivist perspective on learning where students collaborate and work together to form new shared knowledge. Given the importance of collaborative work in the geosciences (both academically and professionally), inquiry into effective teamwork in the geosciences via SSRL would also serve the community.

Recommended Research Strategies

1. Since there have been few studies in the geosciences related to this field of study, there is a strong need to identify the self-regulatory and metacognitive skills that lead to student success in geoscience learning and to determine if these learning skills are similar or different than those identified in other domain specific fields (e.g., chemistry, biology).

2. Similarly, it is important to understand what sorts of skills those that are successful in the geosciences employ and to specifically isolate whether these skills are different between different populations along the novice-expert continuum.

3. Once it is clear what self-regulatory and metacognitive skills are needed by students to succeed in the geosciences, then it will be important to identify ways to support and implement classroom strategies aimed to develop these student skills.

4. Finally, in order to broader larger adoption and propagation of these approaches aimed to support student affect and development of self-regulatory and metacognitive skills, it will be important to design and assess interventions aimed to foster these skills in a variety of learning settings.

Grand Challenge 2:

Inclusion: What are effective strategies in engaging a diverse population of students in their learning and sustaining their interest in the geosciences?

Rationale

In order to increase representation of systemically non-dominant populations in the geosciences, and to ensure success for all students, we must determine what strategies are most effective in engaging students to effectively learn the geoscience content. Even more importantly, we must determine how students can connect to the content in a way that allows them to identify with the content and feel as though they belong within the geoscience community.

Self-regulated learning has origins in socio-cognitive processes, and as such has been hypothesized that it may vary across ethnic and cultural groups (McInerney, 2011). Towards this end, efforts have been made in other disciplines to characterize the experiences and self-regulatory behaviors of diverse populations during both general science learning and the learning of specific science disciplines (e.g., chemistry; Lopez et al., 2013; Tang & Neber, 2008). As students in the geosciences must utilize an important set of cognitive skills (e.g., spatial thinking and abstraction) to find success (e.g., to learn mineral crystallography or draw cross sections), a similar approach should be developed and enacted within the geosciences. Potential differences and/or barriers to students of diverse populations should then be targeted via interventions designed to maximize the potential for both success and equity across all populations.

In addition, there are barriers that exist within the classroom and the institution that need to be identified in order to develop strategies to support students in developing and maintaining interest and connection to the community. Though the generation and encouragement of situational interest in the geosciences is a diverse and nuanced construct that has been approached in recent work related to geoscience learning (van der Hoeven Kraft et al., 2011; LaDue & Pacheco, 2013; van der Hoeven Kraft, 2017). Future inquiry should seek to isolate potential (and/or differential) barriers to students' situational interest and how it can be sustained during course activities and instructional support. Additionally, if students can effectively learn the content, but are not supported or feel disconnected from the community, they will likely not persist regardless of their comprehension (Chang et al., 2014; Callahan et al, 2017). The strategies that emerge as a result of these potential barriers may look different across different populations and contexts, so future inquiry should seek to investigate and eventually attempt to mitigate potential barriers.

Recommended Research Strategies

1. Since self-regulatory learning has been hypothesized to vary among socioeconomic and ethnic groups, it is important to identify successful strategies that engage and support diverse student populations in the geosciences, and understand what, if any, barriers prevent such engagement.

2. Once a variety of self-regulatory learning approaches have been identified for specific populations it will be important to measure the impact of such developed strategies on student learning and equity across populations in the geoscience classroom.

Grand Challenge 3:

Assessment: How can we measure student experiences in the geosciences through the lens of self-regulation, motivation and affect using the most cutting edge research technology and methodologies?

Rationale

There currently exists established methods, tools, and instruments within and outside of the geoscience education community (e.g., educational psychology, science education, other discipline based education fields, and cognitive science) for measuring affect (for a geoscience perspective, see McConnell & van der Hoeven Kraft, 2011) and processes associated with self-regulated learning (Panadero, 2017). The GER field should leverage and build on these approaches and apply them to the specific learning needs of students as they are engaging with geoscience content and developing skill sets within the variety of geoscience learning settings. Both research grade instruments and surveys, as well as classroom level assessments for instructor use should be targeted.

With the advancements and increases in the technology available to assess student variables in real-time (e.g., classroom response systems, course management systems), focus should be paid to developing novel ways to *measure and record* students' self-regulation, metacognition, and affect during the course of geoscience learning. In addition, technological approaches to measuring these variables should be designed to *promote* self-regulation and metacognitive behaviors during geoscience learning (both in-class and potentially in the field). Directed feedback related to the success and relative frequency of learning strategy use during technology-based learning has been shown to be effective in fostering self-regulative behavior (e.g., Fernandez & Yemet, 2017), improving metacognitive thought (e.g., Callender, Franco-Watkins, & Roberts, 2016) and increasing performance of students (e.g., Fernandez & Yemet, 2017). Additionally, real-time measurements of student engagement through wearable skin conductance devices (known as galvanic skin response or GSR) have been made in geoscience classrooms (McNeal et al., 2014). This technology can perhaps support both students and instructors in their self-assessment of their learning and teaching. Consequently, future technology should be designed to assess students' learning process in addition to their level of content knowledge. Such instruments have the potential to yield more effective geoscience learning (and teaching).

Recommended Research Strategies

1. Given there are existing methods and approaches in other fields that can be leveraged by geoscience educators, it is important to explore the literature and expertise from fields outside the geosciences (education psychology, science education, cognitive science, other STEM discipline-based education fields) to ensure we are using the most valid, reliable, and up to date instruments, techniques, and methodologies.

2. To ensure these instruments and methodologies are valid within the context of the geosciences, tests (e.g., lab based studies) need to be conducted with appropriate populations and disciplinary content using these existing techniques and tools. After validation occurs, they can then be applied more broadly and used in geoscience classrooms and field environments.

Grand Challenge 4:

Educators: How support the geoscience community in learning and implementing classroom strategies that are known to be effective in supporting students affect, metacognition and self-regulation of learning?

Rationale

It should not be assumed that students arrive in geoscience courses with the ability to successfully self-regulate their learning or to use metacognitive strategies. Faculty guidance is vital for coaching students to be self-regulated learners as these skills are not guaranteed (e.g., Pressley & Ghatala, 1990) and in most cases must be explicitly taught to students for greatest effectiveness (Schraw & Gutierrez, 2015). In order for Grand Challenges 1 and 2 in this research theme to be implemented broadly and successfully, instructors must be knowledgeable and comfortable using classroom strategies related to affect, metacognition, and self-regulation of learning. With these skills at their fingertips, members of the geoscience community will be a valuable resource for students who are not familiar with (or even aware of) strategies to take control of their own learning.

Instructors' self-efficacy for teaching both the science content *and the learning strategies* has been isolated as an important factor in the instructor's decision to provide students opportunities for self-regulation and metacognitive support (Schraw, Crippen, & Hartley, 2006). As a result, dissemination of effective, yet accessible, approaches to teaching learning strategies as related to the geosciences should be addressed. These dissemination strategies may include faculty professional development, such as face-to-face workshops and webinars, and published research studies that focus on adoption strategies in various learning environments. Other options include content-based activities that are specifically designed to include built-in pedagogical support of students' self-regulation and metacognition (e.g., reflection exercises, self-regulatory prompts).

Barriers to helping instructors learn about these strategies can be psychological (e.g., instructors' resistance to change/lack of interest), institutional (e.g., lack of support to make changes by administrators), and logistical (e.g., no time/funds to attend professional development workshops). Regardless of these potential barriers, however, effective professional development (e.g., On the Cutting Edge) has been shown to impact the diversity of teaching practices educators employ, with even one-time participation in a workshop with peers leading to changes in teaching practice (Manduca et al., 2017) or teaching beliefs (Chapman, 2017). Though these results were largely in relation to the adoption of active learning strategies and/or the development of reformed teaching beliefs, one may assume that similar change may be elicited via professional development more targeted towards the adoption of practices that specifically support the self-regulatory, metacognitive, and affective aspects of students' learning in the geosciences. Furthermore, this assumption of transferability can be an additional direction of future research.

Recommended Research Strategies

Since the instructor needs to guide the learner in developing self-regulatory and metacognitive skills, it is important that we better understand the geoscience practitioner and administrator community and how to support the implementation of these skills by instructors in their classrooms.

To accomplish this task, three strategies have been outlined below:

1. Determine the relationship between attitudes about and adoption of approaches that support student development of self-regulation, metacognition and affect across different members of the geoscience community (practitioners and administrators) from those that represent both formal and informal learning environments.

2. Take inventory of faculty professional development programs inside and out of the geosciences that have been successful in employing self-regulation, metacognition, and affect in their pedagogical contexts and leverage successful approaches and dissemination methods in order to best support geoscience educators in adopting these approaches.

3. Design, implement, and evaluate professional development programs which aim to develop teaching and learning strategies that incorporate supporting student self-regulation, metacognition, and affect for all geoscience educator ranks/positions (e.g., Teaching Assistants, Post-Doctoral Scholars, Instructors, Faculty, Administrators, etc.) and learning settings (e.g., community colleges, Historically Black Colleges and Universities, Minority Serving Universities, Primarily White Institutions, Four-Year Intuitions, Research Universities, etc.).

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Figures

Figure 1.
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