Full Name
Anne Gold

Home Department
Cooperative Institute for Research in Environmental Sciences (CIRES)

Email Address
anne.u.gold@colorado.edu

By submitting this application, I confirm that, if selected to receive a Chancellor's Award for Excellence in STEM Education, I will:

- ✓ Attend and be recognized at the annual Symposium on STEM Education (fall 2014).
- ✓ Give a brief introduction (~10-15 min) to my project at DBER in fall 2014.
- ✓ Actively engage in the CU-Boulder STEM education community by attending weekly DBER seminars and Chancellor's Fellow events when possible.
- ✓ Present my work to the STEM education community by giving at least one DBER seminar, OR, if that is an impossibility, I will give a talk that the CU-Boulder STEM education community is invited to attend.
- ✓ Submit a 1000 to 3000-word report detailing the outcomes of the project at the end of the funding period

Investigating the Impact of Spatial Reasoning Training on Skill Development, Retention, and the Gender Gap in Geology

Proposal for Chancellor's Awards for Excellence in STEM Education 2014

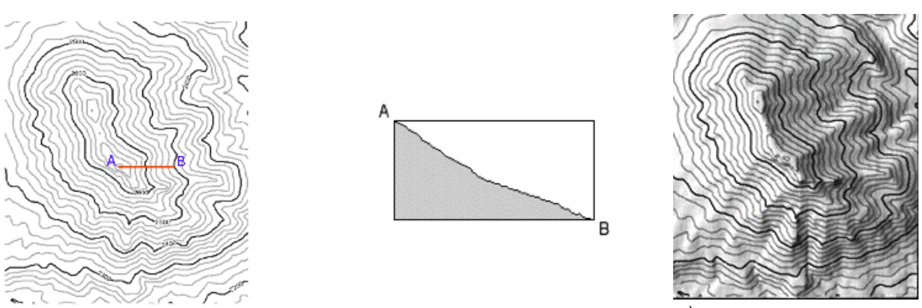
Dr. Anne Gold
Cooperative Institute for Research in Environmental Sciences (CIRES)

SUMMARY

Spatial reasoning is a key skill for student success in Science, Technology, Engineering, and Math (STEM) disciplines in general and for students in geosciences in particular. Reading a topographic map (Figure 1), recognizing crystal lattices in minerals, understanding faulting in rock outcrops, and interpreting seismic profiles or atmospheric circulation patterns are just a few examples of spatially demanding geoscience tasks. Geoscientists must also reason about timescales at which spatially complex processes occur. However, spatial reasoning is neither explicitly trained, nor evenly distributed, among students. A lack of spatial reasoning skills has been shown to be a barrier to success in the geosciences, and for STEM disciplines in general.

The work proposed for this Chancellor's Awards for Excellence in STEM Education will result in a toolkit for testing and training undergraduate student spatial reasoning skills and will provide insight into successful interventions for improving students' spatial skills. With this toolkit, I will study 1) the development of spatial reasoning skills in students enrolled in undergraduate geology classes; 2) the effect of spatial reasoning training on student performance; and 3) the effect of spatial reasoning training on perceived career interest and retention in the geosciences or STEM disciplines in general.

I propose to study the effect of spatial reasoning training in students enrolled in undergraduate geology courses. I hypothesize that students who receive spatial reasoning training will improve their performance on spatial reasoning testing. Furthermore, I hypothesize that spatial reasoning training will result in better course performance and a greater likelihood of pursuing a geoscience major than a control group who does not receive this training. I also hypothesize an intervention will have a larger effect on females than on males.



a) ***b)*** ***c)***

Fig. 1. One spatial skill required for many geosciences disciplines is map reading and interpretation of contour lines; a) shows the 2D contour lines of a map, b) shows the interpretation of the map along a profile line, and c) shows how a spatially-trained viewer may translate the map into a 3D image. (Images from Piburn et al., 2002.)

PROJECT RATIONALE

STEM workers are the drivers behind innovation in the U.S. economy, making up about a quarter of the professional labor force (DPE, 2012). Demand for these workers is growing significantly faster than the average U.S. job market and is currently not matched by STEM graduates (PCAST, 2010; DPE, 2012). President Obama made increasing STEM graduates a national priority through the 2010 America Competes Act. The American Geosciences Institute (AGI, 2011) projects an aggregated jobs increase for geoscientists of 35% between 2008 and 2015, and anticipates that the petroleum industry, the highest paying geoscience field, faces a projected unmet demand of 13,000 workers by 2030.

Colorado offers a natural laboratory for the geosciences with its diverse landscape of towering mountains, expansive forests, grassy plains, and deserts. Colorado is also home to numerous geoscience laboratories and research institutes, many of which are located in the Boulder area and are affiliated with CU. Geoscience programs at the University of Colorado were again highly rated in a national ranking ("Geology – 9th"; "Earth Science 23rd" - US News, March 11, 2014). The combination of academic excellence and access to abundant study sites provides a unique opportunity to spark interest in and inspire CU students for a career in the geosciences. With the proposed work, we strive to develop tools which could increase the number of CU students graduating in the geosciences.

Most geoscience tasks require spatial reasoning. Thus, spatial cognition is the foundation of all geoscience disciplines (Chadwick, 1978; Kastens & Ishikawa, 2006; Kastens et al., 2009; Liben & Titus, 2012; Shipley et al., 2013). However, spatial reasoning skills are not systematically instructed in secondary schools (National Research Council, 2006), assessed among incoming undergraduate students (Reynolds, 2012), or explicitly included in instruction for STEM disciplines, including the geosciences.

What is spatial reasoning? It is not a single skill but rather a "collection of cognitive skills" (National Research Council, 2006). Spatial reasoning skills can be isolated, and are not the same as discipline-specific experts' reasoning skills (Uttal & Cohen, 2012). For example, Ormand et al. (2014) focus on three different types of spatial thinking skills–i) mental rotation (visualizing the effect of rotating an object), ii) penetrative thinking (visualizing spatial relations inside and object), and iii) disembedding (isolating and attending to one aspect of a complex display or scene).

Spatial skills are unevenly distributed in the population and therefore also in incoming geoscience undergraduates (Kali & Orion, 1996; National Research Council, 2006; Liben & Titus, 2012; Ormand et al., 2014), which presents a challenge to university instructors. This uneven playing field allows some students to perform geoscience tasks easily while others struggle despite their efforts (Kastens et al., 2009). Male students tend to outperform female students on spatial reasoning tests (Lord, 1987; Kali & Orion, 1996; Guillot, et al. 2007; Sorby, 2009; Titus & Horsman, 2009), but when students receive training, females improve their spatial skills more rapidly than males (Lord 1987; Sorby, 2001). Addressing spatial abilities early in the college experience might therefore be effective in narrowing the gender gap in the geosciences (AGI, 2011) and will be one focus of this study.

Studies that psychometrically assessed students' spatial reasoning skills and measured their success in geoscience show that the level of spatial reasoning skills predicts introductory students' performance in the geosciences (Titus & Horsman, 2009; Lee & Bednarz, 2009), and can also be an indicator of entrance into geoscience occupations (Dyar, 2012). Therefore, improving spatial reasoning skills among introductory students may help recruit and retain geoscience majors.

Can spatial reasoning be trained? The National Research Council (2006) points out that spatial reasoning is a 'basic and essential skill that can be learned' and should be included in curricula. Empirical studies support this and show increases in spatial reasoning skills through instructional interventions (Lord, 1985; 1987; Sorby, 2009; 2001; Hall-Wallace & McAuliffe, 2002; Reynolds et al., 2006; Titus & Horsman, 2009; Uttal & Cohen, 2012) as well as play-based intervention (Green & Bavelier, 2003; Terlecki et al., 2008). Spatial training provides students with a toolset for solving spatial problems and increases their success in the discipline. For example, longitudinal studies showed that students with weak spatial reasoning skills who received explicit training earned better grades in subsequent STEM courses (Sorby, 2001; 2009). Many studies have tested spatial abilities and curricular interventions in students; however, only a few empirical studies have yet been conducted addressing the effect of spatial training on student performance and retention in STEM disciplines. I am not aware of an empirical and controlled study that tested the effect of spatial reasoning training on undergraduate students' performance and retention in STEM disciplines.

When is the best timing for training of spatial reasoning skills? Spatial skills appear to be an early gatekeeper for success in the geosciences. Research results indicate that the importance of spatial reasoning decreases with increased expertise of an individual (summarized in Uttal & Cohen, 2012). While spatial reasoning skills are a predictor of novice success in the field, it has been shown that expert performance is not strongly correlated with spatial abilities (Hambrick et al., 2011). Therefore, any interventions aimed at improving geoscience skills need to target students early in their college career to increase retention or influence students choosing a geoscience or STEM major. Increasing student success in introductory courses is also important because only 20% of geoscience graduates report that they declared their major when first enrolling in college; the majority choose a geoscience major at some point during their college education (AGI, 2013), likely inspired through positive experiences during their coursework.

What is the importance of spatial reasoning in other STEM disciplines? While the demand of spatial ability in the geosciences is obvious and has been described above, it is also a key skill in most other STEM fields. Large-scale longitudinal studies show that spatial reasoning assessment predicts success in STEM disciplines in general (Shea et al., 2001; Wai et al., 2009). A recent comprehensive review of spatial thinking in STEM disciplines (Uttal & Cohen, 2012) finds that spatial reasoning skills are highly transferable between STEM disciplines. The results of our proposed work at CU would therefore be relevant to all STEM disciplines, and help increase student performance and retention in the disciplines. Our findings might inform instruction across STEM fields at CU.

In summary, I propose to assess spatial reasoning skills in undergraduate geology students, and then test the effect of spatial reasoning training modules on students' development of spatial reasoning skills, course performance, and retention. Research questions for this study are the following:

1) What is the distribution of spatial reasoning skills in students enrolled in undergraduate geology courses (with specific attention to gender, major, and standardized test scores)?
2) In which ways do spatial reasoning skills change throughout participation in an undergraduate geology course – both for students who receive a treatment and a control group?

3) Does the spatial training affect student course performance, interest in geoscience and STEM disciplines, or retention in the field?
4) What is the effect of different types of interventions (weekly assignments vs. one-time training) on spatial reasoning skills?
5) How well do students retain spatial reasoning skills after completion of a training program during an undergraduate geology course?
6) What effect does completing the pre-/post-test have on spatial reasoning skills (test-retest effect)?

STUDY DESIGN AND METHODOLOGY

Team:
I am a geoscientist by training (diploma and dissertation in geography, master's degree in Geographic Information System and Sciences, postdoc in geology) with training in spatial reasoning as part of my master's degree. I am now part of the CIRES Education and Outreach group focusing on geoscience education. I will conduct this study in collaboration with David Budd, Jennifer Stempien, and Karl Mueller, faculty members of the Department of Geological Sciences. CIRES' media expert David Oonk will provide technical support in developing and providing online access to the spatial training modules. CIRES undergraduate students will help with data preparation and interview transcriptions.

Test Instrument
A number of different test instruments have been developed (Vandenberg & Kuse, 1978; Kali & Orion, 1996; Bodner & Guay, 1997; Lee & Bednarz, 2009); see Figure 2 for an example. In order to study the breadth of spatial abilities in students, a suite of spatial reasoning psychometric tests are combined when assessing spatial reasoning skills (Riggs, 2009; Sorby, 2009; Ormand et al., 2014).

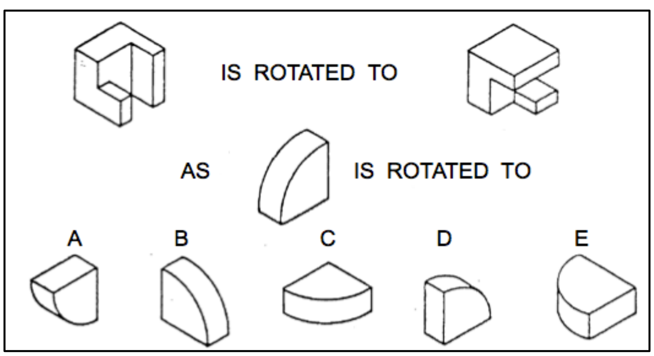


Fig. 2. Example of test item from Purdue Visualization of Rotations Test (Bodner & Guay, 1997).

In this study we will follow the testing protocol used in Ormand et al., (2014), which is based on a combination of different validated test instruments (see above). The test instrument will be administered both as a pre-test (beginning of semester) and a post-test (end of semester). We will gather additional information about the students to investigate the influences on spatial reasoning test performance by factors such as gender, other geoscience courses taken (both in college and high school), GPA, SAT score (to account for general performance on standardized tests), major, and career goals. We will attempt to obtain this information from the registrar; other items will be requested as self-report items on the pre-test (e.g., high school geoscience courses). The test will take about 15 to 20 minutes to complete (pers. conversation with E. Riggs, 2014).

Development of Training Modules
Not many activities have been developed that explicitly aim to increase spatial skills in the geosciences. We will develop a training program that includes 12 modules that will each take about 15 minutes to complete. Each module will have two parts–i) mental rotation activities and spatial visualizations that are abstract and non-geology-focused (items similar to Fig. 2) and ii) parallel spatial activities that have an explicit geology focus (items similar to Fig. 3). We will draw examples from different geology subdisciplines (e.g., mineralogy, structural geology, mapping). To accommodate multiple learning styles, we will include a variety of 2D and 3D animations, static visualizations, and hands-on activities. We will modify activities from existing spatial reasoning training programs (Kali et al., 1997; Sorby et al., 2003; Reynolds et al., 2006; Rapp et al., 2007), base them on existing test items, and develop new ones (Fig. 3). None of the test items on the test instrument will be included in the trainings modules.

Students will be provided with worksheets to help develop their answers but they will complete the activity by checking one of up to six multiple-choice answers. Students will be asked to either upload a smartphone photo or a scan of their worksheets (for interventions that occur as homework assignments) or hand in their worksheets (for interventions that occur during class time). Sketches will be used to improve the quality of the response items. The training modules will be developed in a virtual space and linked into the D2L-Course Platform to facilitate easy integration into homework assignments and the course record. Completing the spatial reasoning assignments will be part of the graded homework. Completion alone will result in the full credit; performance on the test will not be included in the grading of this assignment.

Validation of Training Modules: Prior to administering the training modules we will ask three students to complete the test modules in a think-aloud interview. We will recruit one undergraduate student with a non-geoscience background, one undergraduate student with a geoscience background, and one advanced undergraduate student who is focusing on a spatially demanding subdiscipline (e.g., structural geology). Based on the transcribed think-aloud interviews, we will tweak the training modules.

Results from the student responses to the activities in the trainings modules during fall 2014 will be analyzed. Results from both the multiple-choice responses and the worksheets will be used to improve the multiple-choice answer options.

Implementation
Over academic year 2014-2015, three instructors will implement pre-post spatial reasoning tests to all students in three geology courses. Each instructor will implement one of three training interventions, as described below (see letters of commitment).

We are planning to run three different types of interventions that vary in frequency and administration style, but not in content, to test the effect of variable frequency of interventions:
Intervention type A: Weekly homework assignments (1 module/week)
Intervention type B: Modules administered as part of a lab (1 module/week)
Intervention type C: Compressed in-class training using the developed modules at the beginning of the semester followed by a "refresher" activity in the middle of the semester (either as homework assignment or in class).

Implementation I: GEOL 1010 in fall 2014 – two course sections (~160-190 students each) are being taught in parallel by the same instructor (J. Stempien). One section will serve as a treatment group that will complete the training modules using intervention type A (weekly homework). The other section, a control group, will not receive any intervention.

Implementation II: GEOL 3120 in fall 2014 – one section (~70 students) with two lab sections (instructor: K. Mueller). One lab section will complete the spatial trainings in their weekly lab schedule (intervention type B), the other lab section will serve as the control group. This course is taken by declared geology majors and is a challenging course after which many students drop out of the discipline.

Implementation III: GEOL 1010 in spring 2015 – a single section (~160-190 students) will be divided into a treatment and a control group (instructor: D. Budd). The treatment group will receive spatial training in the first week during the regular class time (intervention type C); the control group will not. In the middle of the semester, the treatment group will receive a refresher (likely as a homework assignment).

Implementation IV: 20 CU freshmen students who are not enrolled in geoscience classes will complete the pre-test, post-test, and retention spatial skills tests, at the same frequency as the treatment and control groups of this study, in order to measure the learning gains in students that can be only attributed to repeatedly completing the same test and not to learning in a geoscience course. These students will be recruited and provided with an incentive of $25.

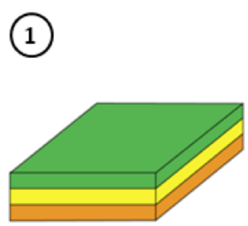
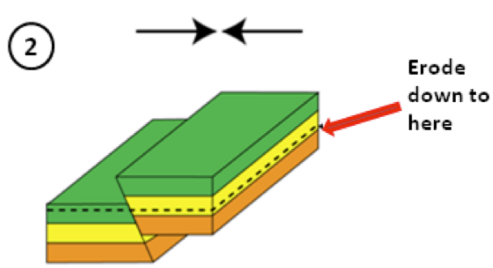
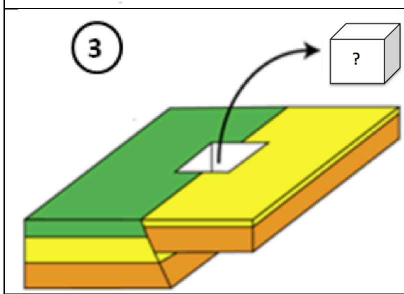
	**Possible Training Activity:** Animation of geological process is played in slow motion; it starts out with horizontal layers.
	Animation shows how compression results in faulting; text and voice-over explain the process of faulting and subsequent erosion.
	**Activity 1:** Draw the faulted layers in the geologic block on your worksheet – make sure to draw all three visible sides.

Fig. 3. Example activity for spatial reasoning training. Students will sketch on worksheets, then choose an answer from one of six choices within D2L. Sketches are handed in along with the digital answers (images modified from BGeology http://voyager.cs.bgsu.edu/topo).

Retention of spatial reasoning skills: A subset of students who participated in the implementation groups (I or II) will be asked to complete the spatial skills test in the first week of the following semester to measure retention of spatial skills (about one month after the intervention was completed). We will use power analysis to determine the ideal number of students from these two interventions to be included in this retention test. Students will be provided with an incentive of $15.

Data Analysis

Data: We will analyze our datasets using regression statistics to answer our research questions (see Rationale above) about the effect of spatial reasoning training on post-test performance and retention. We will also disaggregate the data based on type of intervention, gender, major, SAT scores, and other available information and analyze effects on the treatment group.

Evaluation

Student and Instructor Interviews: We will recruit a total of 15 students for interviews about their experience and perception of their own spatial skills, their career goals, and their interest in STEM careers; they will include 5 students from each intervention (I-III). Students will be provided with an incentive of $20. We will recruit students with a range of spatial abilities, spatial learning gains, declared majors, and overall course performance. We will also interview the three instructors who participated in the study. Both interview protocols will be developed based on experiences with the first implementation round in fall 2014. Interview transcripts will be analyzed for themes related to the impact of spatial reasoning training on their learning and choice of major.

Tracking Student Information: We work with CU's Office of Planning, Budget, and Analysis (PBA) to track student information about college career of students (both our control groups and the treatment groups), tracking their choice of major, year of graduation, possible college drop-out, and overall performance for at least the year following the interventions and (pending additional funding) over their college career at CU.

The following table shows the data we will use to study each of the research questions:

Research Question	Data collection
RQ 1) What is the distribution of spatial reasoning skills in students enrolled in undergraduate geology courses (with specific attention to gender, major, standardized test scores)?	Pre-test
RQ 2) In which ways do spatial reasoning skills change throughout participation in an undergraduate geology course – both for students who receive a treatment and a control group?	Pre-test; post-test; retention test
RQ 3) Does the spatial training affect student course performance, interest in geoscience and STEM disciplines, or retention in the field?	Information from pre- and post-test; student interviews; enrollment and career data from CU's Office of PBA;
RQ 4) What is the effect of different types of interventions (weekly assignments vs. one-time training) on spatial reasoning skills?	Pre-test; posttest for the different treatment groups; student interviews
RQ 5) How well do students retain spatial reasoning skills after completion of a training program during an undergraduate geology course?	Retention test
RQ 6) What effect does completing the pre-/post-test	Test-retest with non-geoscience

have on spatial reasoning skills (test-retest effect)?	students

Overall evaluation of project success:
We consider the project successful if the following deliverables have been completed:

- 12 training modules targeting spatial skills
- Completed study on both interventions including pre- and post-test for both control and treatment groups (including proof of completed training for treatment group)
- Analysis and disaggregation of datasets
- Results from retention test
- Results from test-retest control group
- Results of qualitative data analysis of student and instructor interviews.
- Presentation of results at national conference
- Submission of results for publication

Advisors to the project:

- Carol Ormand (Science Education Resource Center, Carleton College) – Lead PI on the NSF funded "Spatial Thinking Workbook" project (June 2011-May 2015).
- Susan Buhr Sullivan (CIRES Education and Outreach Director) – has extensive experience in education, outreach, and project evaluation.

PROJECT BUDGET

Two months of salary are requested in the budget to support my work on the project over the summer and fall of 2014 and spring of 2015. David Oonks' salary will support his work in designing and making the training modules available online. The incentives for student participation and support of undergraduate students are necessary for the data collection and analysis.

A total of $10,000 is requested for conducting the proposed study. Budget items are:

- 1.4 months of my salary ($7,300) to lead the study, design the test and implementations, and analyze the data
- 43 hours of salary for David Oonk ($900) for his work in designing and making the training modules available online
- 40 hours of undergraduate hourly student salary ($450) for help with the implementation and data processing
- Incentives for CU students who participate in the test-retest study ($500)
- Incentives for study participants who participate in the retention study ($300)
- Incentives for study participants who participate in the interviews ($450)
- Acquisition of books and CDs about existing spatial trainings ($100)

TIMEFRAME FOR PROJECT:

The table below outlines the broad timeframe for the project.

	Summer 2014	Fall 2014	Winter 2014	Spring 2015	Summer 2015
IRB application	x				
Trainings module development	x				
Revision of training modules			x		(x)
Implementation I (pre-test, intervention A, post-test) and control group		x			
Implementation II (pre-test, intervention B, post-test) and control group		x			
Implementation I & II – retention test			x		
Instructor and student interviews				x	x
Data Analysis	x		x		x
Implementation III (pre-test, intervention C, post-test) and control group				x	
Implementation III – retention test					x
Implementation IV - test-retest with non-geoscience students				x	
Presentation				x	x
Publication				x	x

PROJECT IMPACTS

Training spatial reasoning will reduce barriers for students to perform geoscience tasks as part of their course work. Improving spatial reasoning skills in introductory geoscience students will likely increase student performance in geoscience and other STEM disciplines and could therefore result in a higher interest and retention in these disciplines. The interventions are likely to have a larger effect on students with lower spatial abilities, such as females and students who were not exposed to spatial reasoning in their childhood or secondary school career. The toolkit that will be developed under this proposed work allows instructors to both measure and improve spatial skills in their students without a large time commitment. If the results of our study demonstrate the effectiveness of interventions, testing and training of spatial reasoning skills could be conducted as part of all introductory geoscience courses. Testing for spatial reasoning skills could also be mandatory prior to course enrollment to avoid student participation in courses for which they are underprepared. Furthermore, the attention to spatial ability of students could also be extended to all incoming students and a test for spatial ability could be included in other CU placement tests like the ALEKS test for mathematics. Students with below average spatial skills could then be offered a training program, independent of their enrollment in a course.

Results from this work will be presented at national conferences and submitted for publication, increasing CU’s visibility and reputation in discipline-based educational research. We plan to expand this pilot work to a full proposal to the National Science Foundation once we have analyzed data gathered in this study in order to explore related questions of how geoscientists learn and to study their trajectory from novice to expert.

Training spatial abilities is likely even more effective for secondary level students, because success in STEM classes at the secondary level has shown to influence students’ interest in STEM fields. We would like to apply what we learn in this study to middle school students and study the effect of boosting spatial reasoning skills on career choices. My home institution, CIRES Education and Outreach, works frequently with secondary teachers and students. The outcomes of this study will directly affect my work with this audience and we are planning to incorporate our findings in future curriculum development and educator professional development projects. Improving student understanding for scales and dimensions across the sciences is part of the recently released Next Generation Science Standards (NGSS, Achieve, 2013). Research-based findings will support the development of new educational materials and allow us to direct the attention of educators to the importance of spatial abilities as part of the new instructional approach demanded by the NGSS.

REFERENCES

Achieve (2013): Next Generation Science Standards. (http://www.nextgenscience.org/next-generation-science-standards)

AGI (American Geosciences Institute) (2011): Status of the Geoscience Workforce 2011. Compiled by L. Gonzales and C. Keane. 39 p.

AGI (American Geosciences Institute) (2013): Status Report of Recent Geoscience Graduates. Compiled by C. Wilson. 28 p.

Bodner, G. M., Guay, R. B. (1997). The Purdue visualization of rotations test. The Chemical Educator, 2(4), 1-17.

Chadwick, P. (1978): Some aspects of the development of geological thinking. Journal of Geology Teaching, 3, p. 142-148.

DPE (Department of Professional Employment), 2012. The Stem Workforce: An Occupational Overview. Factsheet 2012. 7 pages. (online: dpeaflcio.org/wp-content/uploads/The-STEM-workforce-2012.pdf)

Dyar, M.D. (2012): Gender and geoscience specialization as a function of object and spatial visualization skills. In: Kastens, K. & Manduca, C. (eds.): Earth and Mind II: A Synthesis of Research on Thinking and Learning in the Geosciences. The Geological Society of America Special Paper 486, p. 79-83.

Green, C. S., Bavelier, D. (2003). Action video game modifies visual selective attention. Nature, 423(6939), 534-537.

Guillot, A., Champeley, S., Batier, C., Thiriet, P., Collet, C. (2007): Relationship between spatial abilities, mental rotation and functional anatomy learning. Advances in Health Sciences Education, 12, p. 491-507.

Hall-Wallace, M., McAuliffe (2002): Design, Implementation, and evaluation of GIS-based learning materials in an introductory geoscience course. Journal of Geoscience Education, 50, p. 5-14.

Hambrick, D. Z., Libarkin, J.C., Petcovic, H.L., Baker, K.M., Elkins, J., Callahan, C.N., Turner, S.P., Rench, T.A., LaDue, N.D. (2012): A test of the circumvention-of-limits hypothesis in scientific problem solving: The case of geological bedrock mapping. Journal of Experimental Psychology: General, 141, p. 397.

Kali, Y., Orion, N. (1996): Spatial Ability of High-School students in the Perception of Geological Structures. Journal of Research in Science Teaching, 33, p. 369-391.

Kali, Y., Orion, N., Mazor, E. (1997): Software for Assisting High School Students in the Spatial Perception of Geological Structures. Journal of Geoscience Education, 45, p. 10-21.

Kastens, K. A., Agrawal, S., Liben, L. S. (2009). How Students and Field Geologists Reason in Integrating Spatial Observations from Outcrops to Visualize a 3D Geological Structure. International Journal of Science Education, 31, p. 365-393.

Kastens, K., Ishikawa, T. (2006): Spatial thinking in the geosciences and cognitive sciences: A cross-disciplinary look at the intersection of the two fields. In: Manduca, C.A. & Mogk, D.W. (eds.): Earth and Mind: How Geologists Think and Learn about the Earth.

Geological Society of America Special Paper 413, p. 53-76.
Kastens, K., Manduca, C., Cervato, C., Frodeman, R., Goodwin, C., Liben, L., Mogk, D., Spangler, T., Stillings, N., Titus, S., (2009): How Geoscientists Think and Learn. EOS Transactions American Geophysical Union, 90, p. 265-272.
Lee, J., Bednarz, R. (2009): Effect of GIS learning on spatial thinking. Journal of Geography in Higher Education, 33, p. 183-198.
Liben, L., Titus, S. (2012): The importance of spatial thinking for geoscience education: Insights from the crossroads of geoscience and cognitive science. In: Kastens, K. & Manduca, C. (eds.): Earth and Mind II: A Synthesis of Research on Thinking and Learning in the Geosciences. The Geological Society of America Special Paper 486, p. 51-70.
Lord, T. (1985): Enhancing the visual-spatial aptitude of students. Journal of Research in Science Teaching, 22, p. 395-405.
Lord, Thomas R. (1987): A look at spatial abilities in undergraduate women science majors. Journal of Research in Science Teaching 24.8, p. 757-767.
National Research Council (2006): Learning to think spatially: GIS as a support system in K-12 curriculum. Washington, D.C., National Academies Press.
Ormand, C. J., Manduca, C., Shipley, T. F., Tikoff, B., Harwood, C. L., Atit, K., Boone, A. P. (2014). Evaluating Geoscience Students' Spatial Thinking Skills in a Multi-Institutional Classroom Study. Journal of Geoscience Education, 62, p. 146-154.
PCAST (President's Council of Advisors on Science and Technology) (2010): Report to the President. Prepare and Inspire: K-12 Education in Science, Technology, Engineering, and Math (STEM) for America's Future. (online: www.whitehouse.gov/ostp/pcast)
Piburn, M.D., Reynolds, S.J., Leedy, D.E., McAuliffe, C.M., Birk, J.P., Johnson, J.K. (2002): The Hidden Earth: Visualization of Geologic Features and their Subsurface Geometry. Paper presented at National Association for Research in Science Teaching, New Orleans, LA.
Rapp, D. N., Culpepper, S.A., Kirkby, K., Morin, P. (2007): Fostering students' comprehension of topographic maps." Journal of Geoscience Education, 55, p. 5-16.
Reynolds, S. J., Piburn, M. D., Leedy, D. E., McAuliffe, C. M., Birk, J. P., Johnson, J. K. (2006). The Hidden Earth-Interactive, computer-based modules for geoscience learning. Special Papers-Geological Society Of America, 413, 157.
Reynolds, S.J. (2012): Some important aspects of spatial cognition in field geology. In: Kastens, K. & Manduca, C. (eds.): Earth and Mind II: A Synthesis of Research on Thinking and Learning in the Geosciences. The Geological Society of America Special Paper 486, p. 75-77.
Riggs, E.M. (2009): A role for mental rotations in field-based problem solving. Geological Society of America Abstracts with Programs, 41, 7, p. 195.
Shea, D. L., Lubinski, D., Benbow, C. P. (2001): Importance of assessing spatial ability in intellectually talented young adolescents: A 20-year longitudinal study. Journal of Educational Psychology, 93, p. 604.
Shipley, T. F., Tikoff, B., Ormand, C., Manduca, C. (2013): Structural geology practice and learning, from the perspective of cognitive science. Journal of Structural Geology, 54, p. 72-84.
Sorby, S. (2009): Developing spatial cognitive skills among middle school students. Cognitive Processes, 10, p. 312-315.
Sorby, S. A. (2001): A course in spatial visualization and its impact on the retention of female engineering students. Journal of women and minorities in science and engineering, 7, p. 153-172.
Sorby, S., Wysocki, A.F., Baartmans, B.J. (2003): Introduction to 3D Spatial Visualization: An Active Approach (Book & CD)
Terlecki, M. S., Newcombe, N. S., & Little, M. (2008). Durable and generalized effects of spatial

experience on mental rotation: Gender differences in growth patterns. Applied Cognitive Psychology, 22(7), p. 996-1013.
Titus, S., Horsman, E. (2009): Characterizing and improving spatial visualization skills. Journal of Geoscience Education, 57, p. 242-254.
Uttal, D. H., Cohen, C.A. (2012): Spatial thinking and STEM education: When, why and how." Psychology of learning and motivation, 57, p. 147-181.
Vandenberg, S. G., & Kuse, A. R. (1978). Mental rotations, a group test of three-dimensional spatial visualization. Perceptual and motor skills, 47(2), p. 599-604.
Wai, J., Lubinski, D., & Benbow, C. P. (2009). Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance. Journal of Educational Psychology, 101(4), p. 817.

University of Colorado
Boulder
Department of Geological Sciences
2200 Colorado Blvd
Boulder, Colorado 80309-0399

March 24, 2014

Anne Gold
CIRES Education and Outreach Group
University of Colorado
Boulder, CO 80309-0449

Anne:

This letter is to confirm my willingness to working with you on implementing a spatial reasoning intervention in my introductory Geology class (GEOL 1010) in the spring 2015 semester. It will be a large enrollment course (probably 140-160) dominated by non-STEM students seeking A&S core curriculum credits in an introductory science course. I am willing to implement the intervention you design, as well as any assessment tools created to evaluate the intervention. I am also willing to serve as an intermediary between you and the students should the intervention require access to individual students for interviews or the intervention itself (i.e., a test group).

I look forward to working with you.

David A. Budd

David Budd
Professor, Geological Sciences

University of Colorado at Boulder
Department of Geological Sciences
2200 Colorado Blvd, Campus Box 399
Boulder, Colorado 80309-0399

March 31, 2014

Dear Anne

I am writing to express my interest in participating in your proposed study on geospatial reasoning skills. As we have previously discussed I use spatial reasoning in my undergraduate course in structural geology (GEOL 3120) here at CU Boulder. I understand you will require access to the lab sections of the course this fall and I would be pleased to help you with pre and post assessment testing and training modules for the purposes of your study. There are typically about 70 students in the group that could be easily divided into test and control groups. My TA's can also help you with these aspects of your study. I also would like to be involved with producing any papers for the results of your research, or by helping to submit any future proposals to NSF.

Sincerely

Karl Mueller

Karl Mueller, PhD
Associate Professor of Geology
Department of Geological Sciences
University of Colorado
Boulder, Colorado, 80309-0399
Karl.Mueller@colorado.edu

University of Colorado
Boulder
Department of Geological Sciences
2200 Colorado Blvd
Boulder, Colorado 80309-0399

March 26, 2014

Anne Gold
CIRES Education and Outreach Group
University of Colorado
Boulder, CO 80309-0449

Anne:

This letter is to confirm my willingness to working with you on implementing a weekly spatial reasoning intervention in one of my Introductory to Physical Geology (GEOL 1010) Fall 2014 semester sections and to allow pre- and post- semester surveys on spatial reasoning in both sections. The fall GEOL 1010 sections are large enrollment classes, typically between 120-160 students, dominated by non-STEM and undeclared students seeking core curriculum requirements.

I am willing to implement any intervention that you design, along with assessments to evaluate the intervention, to serve as an intermediary between you and the students, and to allow you access to my courses to D2L to implement and evaluate the intervention.

I am looking forward this project and to working with you.

Sincerely

Jennifer Stempien
Instructor
Dept. of Geological Sciences

Dr. Anne U. Gold

Dipl.-Geogr., M.Sc. (GIS) (maiden name: Reuther)

Cooperative Institute for Research in Environmental Science (CIRES)
Education and Outreach Group
University of Colorado at Boulder
Research Lab 2, UCB 449, 1540 30th Street, Boulder, CO, 80303

Phone: 303-735-5514
Fax: 303-735-3644
anne.u.gold@colorado.edu

POSITIONS

since 2010	**Associate Scientist III – Education and Outreach Specialist** Cooperative Institute for Research in Environmental Sciences (CIRES), Boulder, CO
Mar 2007 – Dec 2009	**Program Manager** German Alpine Association, Munich, Germany
Nov 2005 – Feb 2007	**Postdoctoral Fellow** Department of Earth Sciences, Dalhousie University Halifax, Canada
Sep 2002 – Apr 2003	**Teaching Position and Research Assistant** University of Regensburg, Germany, Department of Geography
Jan 2002 – Oct 2005	**Research Assistant** University of Regensburg, Germany, Department of Geography

EXPERTISE

Education / Outreach:

Digital Library: Project manager for NSF/NOAA-funded Climate Literacy and Energy Awareness Network (CLEAN, cleanet.org)– project management, team lead, development of review process for educational resources, identification and review of educational resources, coordination of review process and panels, webpage content development, project marketing - regionally and nationally;

Curriculum Development: Principle Investigator and Curriculum developer on teacher curriculum development project – specifically data-driven curriculum

Teacher Professional Development: Principle Investigator and Delivery of Face-to-face workshops; Online Webinar Format; Massive Open Online Course (MOOC).

Project Evaluation: Evaluator - both formative and summative on teacher professional development projects.

Student Engagement: Principle Investigator on video projects for secondary school students, including mentoring by graduate and undergraduate students.

Education Research Topics: Effectiveness of teaching climate topics, focus on greenhouse effect, development of mental models; assessment techniques.

Science:

Climate Science: Paleoclimatology, Quaternary Geology and Geomorphology – Regional Focus: European Alps, German low elevation mountains, Romania, Russian Altai, Argentina, Maritime Canada.

Geographical Information Systems

Cosmogenic Nuclide Dating Techniques (^{10}Be, ^{26}Al, ^{36}Cl)

ACADEMIC EDUCATION

2002- 2005 **Dissertation - Physical Geography**
University Regensburg, Germany; collaboration with Eidgenössisch Technische Hochschule, Zürich, Switzerland; Department of Earth Sciences, Halifax, Canada

2002-2004 **M.Sc. in Geographical Information Science & Systems (GIS)**
Paris-Lodron University of Salzburg, Austria

1996-2001 **Diploma (German Masters equivalent) in Physical Geography**
University of Regensburg, Germany; University of Colorado (Fulbright stipend); University of Svalbard, Norway

1997–1999 **Teaching assistant, Student assistant**, University of Regensburg, Germany:

THESES

Dissertation: Surface exposure dating of glacial deposits from the last glacial cycle. Evidence from the Eastern Alps, Bavarian Forest, Southern Carpathians and Altai Mountains. (in English, *summa cum laude*)

M.Sc.Thesis: Constraining glacial equilibrium line altitudes (ELA) by different geometrical approaches by applying a Geographic Information System (GIS). A case study from the Kleinen Arbersee glacier, Bavarian Forest, Germany. (in English)

Diploma Thesis: Sustainable Mountaineering - Evaluation and Optimising of a pilot project on sustainable mountaineering in the German Alps (in German, *with honours*)

PUBLICATIONS / CONFERENCE CONTRIBUTIONS

Scientific Publications (see appendix)

- 12 publications in peer-reviewed journals and 3 non peer-reviewed publications
- 1 book (4 reviewers)
- contributions to international conferences and workshops

Articles and contributions for newspapers and non-scientific journals

SYNERGISTIC ACTIVITIES

- American Geophysical Union (AGU) session convener 2013, 2012, 2011, 2010; Geological Society of America (GSA) session convener 2013
- Workshops for National Association of Geoscience Teachers (NAGT) at Geological Society of America meeting (2013), and American Geophysical Union meeting (2013)
- Presentations for secondary students, teachers and informal educators about climate science; Delivery of mock poster session for middle school students
- Reviewer for international scientific and educational journals, Reviewer for grant proposals
- Board member of CU Boulder based Boulder Friends of International Students (since 2010)

ACADEMIC TEACHING / ADVISING STUDENTS

TEACHING CERTIFICATION

2005 – Certificate for teaching at university level issued by the state of Bavaria, Germany
(137 work units in effective teaching methods, presentation, exam and evaluation techniques)

TEACHING (COLLEGE LEVEL)

- Introductory Courses (Geomorphology, Basic Geography, Aerial Image Interpretation)
- Advanced Courses (Snowhydrology, Physical Geography of Svalbard)
- Field trips and field schools (Avalanche Protection, Svalbard, Altai Mountains)

ADVISING (Diploma students – German equivalent of Masters degree)

2008 – Human Geography - Thomas Kuhnt;

2006 – Physical Geography - Katja Förster

2005 – Physical Geography - Christian Geiger

SCHOLARSHIPS / AWARDS

2006	**Paul-Wolstedt Award** of the German Quaternary Association – dissertation was recognized as a significant and outstanding contribution to Quaternary research
2005–2007	**Postdoctoral Fellowship** awarded by the German Academic Exchange Council (DAAD)
2003–2004	**Scholarship for Young Researchers** by Association of Geomorphologists; **Scholarship for Female Scientists** at University of Regensburg; **Scholarship to Support International Scientific Relations** at University of Regensburg; **DAAD Field Trip Scholarship**
2002	**DAAD-Scholarship for Ph.D. candidates**
2002–2005	**Honorary appointment in the advisory board** of the German Mountaineering Association for project on sustainable mountaineering
2001	**Johanna-Löwenherz Award** for organization and leading of an Arctic expedition
2000–2001	**Fulbright Scholarship** – Academic study-abroad year Boulder, Colorado, USA
1993	**Travel/Study scholarship -** Stiftung für Studienreisen e.V. under patronage of UNESCO.

Boulder, April 1, 2012 Anne Gold

Dr. Anne U. Gold
(maiden name Reuther)

Publications in Scientific Journals

BUHR SULLIVAN, S., LEDLEY, T.S., LYNDS, S.,E., **GOLD, A.U**.: Navigating Climate Science in the Classroom: Teacher Preparation, Perceptions and Practices. (accepted for publication in Journal of Geoscience Education).

LEDLEY, T. S., **GOLD, A**., NIEPOLD, F., MCCAFFREY, M., BUHR SULLIVAN, S., MANDUCA, C.A., FOX, S.: Moving Toward Collective Impact in Climate Change Literacy – The Climate Literacy And Energy Awareness Network (CLEAN). (accepted for publication in Journal of Geoscience Education, Jan 2014)

ELLINS, K.K., LEDLEY, T.S., HADDAD, N., MCNEAL, K., **GOLD, A**., LYNDS, S., LIBARKIN, J.: EarthLabs: Supporting Teacher Professional Development to Facilitate Effective Teaching of Climate Science. Journal of Geoscience Education (in press)

KIRK, K., BUHR SULLIVAN, S., **GOLD, A.U**., LEDLEY, S.T., MANDUCA, C.A., MOGK, D.W., WIESE, K.: Sowing the Seeds of Climate Literacy in Today's College Students. Journal of Geoscience Education (submitted for review June 2013)

GOLD, A.U., LEDLEY, T.S., BUHR, S.M., FOX, S., MCCAFFREY, M., NIEPOLD, F., MANDUCA, C. & LYNDS, S. (2012): Peer-Review of Digital Educational Resources—A Rigorous Review Process Developed by the Climate Literacy and Energy Awareness Network (CLEAN). – Journal of Geoscience Education, 60, pp. 295-308.

REUTHER, A.U., FIEBIG, M.C., IVY-OCHS, S., KUBIK, P.W., REITNER, J.M., JERY, H. & HEINE, K. (2011): Deglaciation of a large Piedmont Lobe Glacier in Comparison with a small mountain glacier – new insight from surface exposure dating. Two studies from SE Germany. – E&G Quaternary Science Journal 60 (2), pp. 248-269.

HEINE, K., **REUTHER, A.U.**, THIEKE, H.-U., SCHULZ, R., SCHLAAK, N. & KUBIK, P.W. (2009): Timing of Weichselian ice marginal positions in Brandenburg (northeastern Germany) using cosmogenic in situ ^{10}Be. - Zeitschrift für Geomorphologie 53, pp. 433-454.

IVY-OCHS, S., KERSCHNER, H., **REUTHER, A.**, PREUSSER, F., HEINE, K., MAISCH, M., KUBIK, P.W. & SCHLÜCHTER, C. (2008): Chronology of the last glacial cycle in the northern European Alps. - Journal of Quaternary Science 23, 6-7, pp. 559-573.

REUTHER, A.U., URDEA, P., GEIGER, C., IVY-OCHS, S., NILLER, H.-P., KUBIK, P. & HEINE, K. (2007): The glacial chronology of the Pietrele Valley, Retezat Mountains, Southern Carpathians constrained by ^{10}Be exposure ages and pedological investigations. - Quaternary International 164-165, pp. 151-169.

KUBIK, P.W. & **REUTHER, A.U.** (2007): Attenuation of cosmogenic ^{10}Be production within the first 20 cm below a rock surface. - Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms 259, 1, pp. 616-624.

REUTHER, A.U. (2007): Surface exposure dating of glacial deposits from the last glacial cycle. Evidence from the Eastern Alps, the Bavarian Forest, the Southern Carpathians and the Altai Mountains. - Relief, Klima, Paläoboden, Verlag Schweizerbart 21, Stuttgart, 196 p.

IVY-OCHS, S., KERSCHNER, H., **REUTHER, A.**, MAISCH, M., SAILER, R., SCHAEFER, J., KUBIK, P.W., SYNAL, H.-A. & SCHLÜCHTER, C. (2006): The timing of glacier advances in the northern European Alps based on surface exposure dating with cosmogenic ^{10}Be, ^{26}Al, ^{36}Cl, and ^{21}Ne. - In: L.L. Siame, D.L.

Bourles, E.T. Brown (eds.): In Situ Cosmogenic Nuclides and their Applications in Earth Sciences. Geological Society of America Special Paper 415, pp. 43-60.

REITNER, J. M., **REUTHER, A. U.**, IVY-OCHS, S., HERBST, P., STADLER, H., KUBIK, P. W.& DRAXLER, I. (2006): The sturzstrom event of Feld (Matrei/Eastern Tyrol/Austria): A forgotten catastrophe during early human settlement in the Alps? - In: M. Tessardi-Wackerle (eds.): PANGEO Austria 2006, Innsbruck, pp. 274-275.

REUTHER, A.U., HERGET, J., IVY-OCHS, S., BORODAVCO, P., KUBIK, P.W. & HEINE, K. (2006): Constraining the timing of the most recent cataclysmic flood event from ice-dammed lakes in the Russian Altai mountains, Siberia using cosmogenic in-situ ^{10}Be. - Geology 34, pp. 913 – 916.

REUTHER, A.U., IVY-OCHS, S. & HEINE, K. (2006): Application of surface exposure dating in glacial geomorphology and the interpretation of moraine ages. – Zeitschrift für Geomorphologie NF 142, pp. 335-359.

REUTHER, A.U., GEIGER, C., URDEA, P. & HEINE, K. (2004): Determining the glacial equilibrium line altitude (ELA) for the northern Retezat Mountains, Southern Carpathians and resulting paleoclimatic implications for the last glacial cycle. - Analele Universităţii de Vest din Timişoara, Geografie 16, pp. 9-32.

REUTHER, A. (2002): Die Problematik das Skibergsteigens in der Bergwaldhöhenstufe der Bayerischen Alpen. - Jahrbuch des Vereins zum Schutz der Bergwelt 67, pp. 261-276.

Conference and Workshop Oral Presentations

HARRIS, S.E., **GOLD, A.U.** (2013): Student Mental Models of the Greenhouse Effect: Retention Months After Interventions, American Geophysical Union Fall Meeting, San Francisco.

GOLD, A.U., HARRIS, S.E. (2013): Measuring University students' understanding of the greenhouse effect – a comparison of multiple-choice, short answer and concept sketch assessment tools with respect to students' mental models, American Geophysical Union Fall Meeting, San Francisco.

LEDLEY, TS, **GOLD, A.U**., NIEPOLD, F., MCCAFFREY, M. (2013): The CLEAN Network – Working Toward Collective Impact on Climate Literacy. Fall AGU Meeting, San Francisco.

SULLIVAN, SB, LEDLEY, T.S., KELLOGG, N., **GOLD, A.U**., LYNDS, S., MANDUCA, C. (2013): What to do Next? Supporting Climate Literacy within Next Generation Science Standards. Fall AGU Meeting, San Francisco.

MCNEAL, K., LIBARKIN, J.C., LEDLEY, T.S., **GOLD, A.U**., LYNDS, S.E., HADDAD, N., ELLINS, K.K., BARDAR, E., DUNLAP, C., YOUNGMAN, E. (2013): Development of a Climate Concept Inventory and Assessment of High-school Students Engaged in the EarthLabs Climate Modules. American Geophysical Union Meeting, San Francisco.

MORRISON, D., **GOLD, A.U.** (2013): Climate Literacy and Energy Awareness Network (CLEAN): Instructional Resources for Science Educators. Regional National Science Teacher Association Conference, Denver.

TAYLOR, J., **GOLD, A.U.,** BUHR, S.M., SMITH, L. (2013) Teaching Climate and Energy: Classroom Resources to Support Your Teaching. Regional National Science Teacher Association Conference, Denver.

GOLD, A.U., HARRIS, S.E. (2013): Measuring University Students' Understanding of the Greenhouse Effect. Discipline Based Education Research Group, December 2013

ELLINS, K., LEDLEY, T., HADDAD, N., MCNEAL, K., **GOLD, A**., LYNDS, S., LIBARKIN, J., QUARTINI, E., THIRUMALAI, K., CAVIETTE, M., 2013: Earthlabs: Supporting Teacher Professional Development To Facilitate

Effective Teaching Of Climate Science, Geological Society of America meeting, Denver.

Gold, AU, Ledley, T.S., Kirk, K., Sullivan, S.B., Manduca, C., Lynds, S. (2013): Investigating and Supporting Energy Education as a Component of Climate Education. Geological Society of America Meeting, Denver.

Gold, AU, Ledley, T.S., Sullivan, S.B., Grogan, M., Lynds, S. (2013): Climate Communication and Education – Effective Framework Developed by the Climate Literacy and Energy Awareness Network (CLEAN). Geological Society of America Meeting, Denver.

Harris, S., **Gold, A.** (2013): University students' mental models of the greenhouse effect: a comparison of two learning activities in moving students toward expert thinking , Geological Society of America Meeting, Denver.

Ledley, TS, **Gold, A.U.,** Niepold, F., Grogan, M., Kirk, K., Sullivan, S.B., Lynds, S., McCaffrey, M., Manduca, C.A., Fox, S. (2013): The Climate Literacy and Energy Awareness Network (CLEAN): Leveraging Reviewed Educational Resources and a Diverse Community to Achieve Climate Literacy Goals. Geological Society of America Meeting, Denver.

Sloan, V., Gold, A., Buhr Sullivan, S., Oonk, D., Lynds, S., Ledley, T.S., Manduca, C. (2013): Reaching Middle and High School Teachers through Email Lists, Facebook, and Web Postings the Results of Sharing Clean Climate and Energy Online Teaching Resources. Geological Society of America Meeting, Denver.

Ledley, T.S., **Gold, A.U.** (2013): Climate Literacy and Energy Awareness Network (CLEAN). Supporting Members in Increasing Climate Literacy, Spring 2013 survey. (CLEAN Network call, 9/24/13)

Ledley, T.S., **Gold, A.U**., Kirk, K., Grogan, M. (2013): Integration of the Energy Literacy Principles in the Climate Literacy and Energy Awareness Network (CLEAN) Portal. Presentation for Department of Energy May 6, 2013

Gold. A.U., Buhr, S., Ledley, T.S. (2013): Teaching Climate and Energy: The CLEAN Collection of Peer-Reviewed Climate and Energy Learning Resources. NSTA Conference, San Antonio.

Randolph, G., Niepold, F., **Gold, A.U**., Falcon, P., TeBockhorst, D., McLaughlin, J. (2013): Teaching Climate Science Through Data and Visualizations, presented at the NSTA Conference, San Antonio (April 2013).

Gold, A.U., Ledley, T.S., Buhr, S.M., Manduca, C.A., Fox, S.P., Kirk, K., Grogan, M., Niepold, F., Carley, S., Lynds, S., Howell, C. (2012): Supporting Teachers in Climate Change Instruction – The Climate Literacy and Energy Awareness Network (CLEAN) Tool Kit. Invited talk at American Geophysical Union (AGU) Annual Meeting – December 2012.

Buhr, S., **Gold, A.U.,** Kellagher, E., Ledley, T., Lynds, S. (2012): Supporting Teachers' Needs in Climate Education: Strategies to forestall controversy, develop knowledge and build community Invited talk) American Geophysical Union (December 2012).

Buhr, S., **Gold, A.U.,** Ledley, T., Lynds, S. (2012): Using Evaluation Studies to Understand Educator Needs, Practices and Strategies for Success in Climate Education (Invited talk) American Geophysical Union (December 2012).

Buhr, S., Ledley, T., **Gold, A**., Manduca, C., Fox, S., Kirk, K., Grogan, M., Niepold, F., Lynds, S. (2012): Climate Literacy And Energy Awareness Network (Clean) – Supporting Teacher's Efforts To Prepare Students To Address Environmental Challenges. Geological Society of America Meeting (October 2012).

LEDLEY, T., BUHR, S., **GOLD, A**., (2012): Teaching Climate and Energy well: New reviewed collection of digital teaching materials around climate and energy topics. NSTA conference (April 2012).

HADDAD, N., MCNEAL, K.S., LEDLEY, T.S., ELLINS, K., BARDAR, E., YOUNGMAN, B., DUNLAP, C., LIBARKIN, J., LYNDS, S., BUHR, S., **GOLD, A.** (2012): Earthlabs Workshops: Increasing Teachers' Understanding And Ability To Teach Climate Science. – Geological Society of America Annual Meeting (GSA) - October 2012.

REITNER, J.M., LOMAX, J., IVY-OCHS, S., **GOLD, A.U.**, DRESCHER-SCHNEIDER, R., FIEBIG, M., KERSCHNER, H. (2011) Challenges in deciphering the Last Glacial Cycle in Eastern Alps: The example of the Drau glacier system.

GOLD, A.U. (2011): The CLEAN project. New Climate and Energy Teaching Resource for Educators, "Climate and Colorado's Water Future Workshop", Lakewood, CO (March 2011).

GOLD, A.U., LEDLEY,T.S., MCCAFFREY, M.S., BUHR, S.M., MANDUCA, C.A., NIEPOLD, F., FOX, S., HOWELL, C., LYNDS, S.E. (2010): Climate Literacy and Energy Awareness Network (CLEAN): New collection of high-quality digital teaching materials on climate and energy science. Colorado Science Conference, Denver, CO (November 2010).

GOLD, A.U., LEDLEY,T.S., MCCAFFREY, M.S., BUHR, S.M., MANDUCA, C.A., NIEPOLD, F., FOX, S., HOWELL, C., LYNDS, S.E. (2010): Climate Literacy and Energy Awareness Network (CLEAN): A rigorous peer-review process for building a new collection of high-quality digital teaching materials on climate and energy science. Geological Society of America Fall Meeting, Denver, CO (October 2010).

LEDLEY, T.S. & **GOLD, A.U.** (2010): Climate Literacy and Energy Awareness Network Pathway – Summary of a Rigorous Review Process. NASA GCCE (Global Climate Change Education) Webinar for Principle Investigators. (October 2010).

GOLD, A.U., LEDLEY,T.S., MCCAFFREY, M.S., BUHR, S.M., MANDUCA, C.A., NIEPOLD, F., FOX, S., HOWELL, C., LYNDS, S.E. (2010): Excellent digital teaching materials – summary of a rigorous review process - Climate Literacy And Energy Awareness Network Pathway. Colorado Learning and Teaching with Technology Conference (COLTT), (August 2010).

GOLD, A.U. (2010): Climate Literacy and Energy Awareness Project (CLEAN) – High Quality Climate and Energy Teaching Resources. "Inspiring Climate Change Excellence (ICEE) Workshop, Boulder, CO (June 2010).

REUTHER, A.U., STEA, R.R, GOSSE, J.C. & MCDONALD, F. (2007): Deglaciation of Nova Scotia: a chronostratigraphic approach, Atlantic Geoscience Society (AGS), Moncton, Canada (Feb 2007).

REUTHER, A.U. (2007): "The glacial chronology of the Southern Carpathians, Romania, constrained by 10Be exposure ages and pedological investigations" (Department of Earth Sciences, Dalhousie University, Mar 2007, Halifax, Canada)

REUTHER, A.U. (2006): "The most recent cataclysmic flood event from ice-dammed lakes in the Russian Altai Mountains, Siberia: Evidence, Magnitude, Timing and Impact", Invited talk at Department of Earth and Environmental Sciences, Lehigh University, Oct 2006, Bethlehem, PA, USA:

REUTHER, A.U. (2006): "Dating of a flooding event from ice-dammed lakes in the Russian Altai Mountains" Invited talk in the Bedford Institute of Oceanography, Mar 2006, Dartmouth, Canada.

REUTHER, A.U. (2006): "Reconstructing the Late Glacial and Last Glacial history of the Valle Pietrele, Retezat Mountains, Southern Carpathians" Presentation: Quaternary Research Group, Dalhousie University, Jan 2006, Halifax, Canada:

REUTHER, A.U. (2006): "Climate and paleoclimate in the Andes with a focus on the transition zone". Presentation at the Andes Research Group Workshop, Dalhousie University, Dec 2005, Halifax, Canada.

REUTHER, A.U., STEA, R.R, GOSSE, J.C. & MCDONALD, F. (2006): Deglaciation of Nova Scotia: a chronostratigraphic approach. First results. Atlantic Canada Ice Dynamics (ACID)-Workshop, Halifax, Canada (Oct 2006)

REITNER, J., **REUTHER, A.U.**, IVY-OCHS, S., HERBST, P., STADLER, H., KUBIK, P. & DRAXLER, I. (2006): The Sturzstrom event of Feld (Matrei / Eastern Tyrol / Austria). A forgotten Catastrophe during early human settlement in the Alps? Deutsche Quartär Vereinigung (DEUQUA) Conference, Bonn, Germany (Jul 2006).

KUBIK, P.W. & **REUTHER, A.U.** (2005): Attenuation of cosmogenic ^{10}Be production within the first 20 cm below a rock surface. *10th* Accelerator Mass Spectrometry *(*AMS) Congress, Lawrence Livermore California, USA (Sep 2005).

REUTHER, A.U., IVY-OCHS, S., FIEBIG, M.C., KUBIK, P.W. & HEINE, K. (2005): Dating of the LGM: Attempts from the type-region of the Wuermian in the South German Alpine Foreland and from the Central German Highlands. Subcommission on European Quaternary Stratigraphy (SEQS) Conference, Bern, Switzerland (Sep 2005).

REUTHER, A.U., URDEA, P., Ivy-Ochs, S., Geiger, C., Kubik, P.W. & HEINE, K. (2004): Reconstructing the glacial history of the Valle Pietrele, Retezat Mountains, Southern Carpathians and the paleoclimatic implications of the last glacial cycle constrained from surface exposure ages (^{10}Be) and pedological records. Subcommission on European Quaternary Stratigraphy (SEQS) Conference, Bern, Switzerland (Sep 2005).

GEIGER, C., **REUTHER, A.U.**, URDEA, P. & HEINE, K. (2004): Constraining the Late Glacial history of the Valle Pietrele, Retezat Mountains, using GIS-based equilibrium line of altitude (ELA) modelling, supported by pedological field observation. International Workshop on Alpine Geomorphology and Mountain Hazards, Fagaras Mountains, Rumania (Sep 2004).

REUTHER, A.U., URDEA, P., Ivy-Ochs, S., Geiger, C., Kubik, P.W. & HEINE, K. (2004): Reconstructing the Last Glacial and Late Glacial history of the Valle Pietrele, Retezat Mountains, Southern Carpathians, using surface exposure dating with in-situ produced ^{10}Be. International Workshop on Alpine Geomorphology and Mountain Hazards, Fagaras Mountains, Rumania (Sep 2004).

REUTHER, A.U., URDEA, P., Ivy-Ochs, S., Geiger, C., Kubik, P.W. & HEINE, K. (2004): Rekonstruktion der letztglazialen Vergletscherung des Valle Pietrele, Retezat Gebirge, Südkarpaten. Datierungen mit kosmogenem, in-situ produziertem ^{10}Be gestützt durch pedologische Untersuchungen. Arbeitskreis (AK) für Geomorphologie Conference, Heidelberg, Germany (Oct 2004).

REUTHER, A.U. & HEINE, K. (2004): Vergletscherung des Bayerischen Waldes am Beispiel des Kleinen Arberseegletschers und erste Ergebnisse vom Isar-Loisach Gletscher- Datierungen mit in-situ produziertem, kosmogenem ^{10}Be. DEUQUA Subkommission Alpenvorland und Quartär (AGAQ) Conference (04/04), Bern, Switzerland (Apr 2004).

Conference and Workshop Poster Presentations

LYNDS, S., **GOLD, A.,** MCNEAL, K.S., LIBARKIN, J., SULLIVAN, S.B., LEDLEY, T., HADDAD, N., ELLINS, K. (2013): Investigating Climate Science Misconceptions Using a Teacher Professional Development

Workshop Registration Survey. American Geophysical Union Meeting, San Francisco.

NIEPOLD, F, LEDLEY, T.S., **GOLD, A.U**., BRESLYN, W.G., CARLEY, S. (2013): Improving the Nation's Climate Literacy Through the Next Generation Science Standards. Fall American Geophysical Union Meeting, San Francisco.

GROGAN, M., NIEPOLD, F., LEDLEY, T.S., **GOLD, A.U.,** BRESLYN, W.G., CARLEY, S. (2013): Improving the Nation's Climate Literacy through the Next Generation Science Standards, American Geophysical Union Fall Meeting, San Francisco.

LEDLEY, TS, **GOLD, A.U**., SULLIVAN, S.B., MANDUCA, C.A., FOX, S. , KIRK, K., GROGAN, M., NIEPOLD, K. (2013): Climate Literacy and Energy Awareness Network (CLEAN) – Providing Reviewed Educational Resources to Enhance the Effective Use of Earth Science Data and Knowledge. ESIP Federation Meeting, Chapel Hill.

GOLD, A.U., HARRIS, S. (2013): Studying effective approaches of teaching the Greenhouse Effect. iSTEM event, May 5, 2013

GOLD, A.U., BUHR, S.S., KELLAGHER, E., MORRISON, D., LYNDS, S.E. (2013): Inspiring Climate Education Excellence (ICEE): Navigating climate instruction in the secondary science classroom, Triagency Meeting in Washington, DC.

GOLD, A.U., BUHR, S.M., LEDLEY, T.S., MANDUCA, C.A., NIEPOLD, F., LYNDS, S.E. (2013): Teaching tools offered by the Climate Literacy and Energy Awareness Network (CLEAN). CIRES Rendez Vous 2013.

GOLD, A.U., MCCAFFREY, M.S., BUHR, S.M., LYNDS, S.E. (2011): The Climate Literacy and Energy Awareness (CLEAN) collection of peer-reviewed high-quality digital teaching materials. CIRES Rendez-Vous (accepted).

LEDLEY, T.S., MCCAFFREY, M.S., BUHR, S.M., **GOLD, A.U**., LYNDS, S.E., MANDUCA, C.A., FOX, S., NIEPOLD, F., HOWELL, C. (2010): Climate Literacy and Energy Awareness Network (CLEAN) Pathway - Teaching Climate and Energy Science: Teaching materials, Professional Development, Social Networking. iSTEM Meeting at CU Boulder (July 2010).

LEDLEY, T.S., GROGAN, M., LOCKWOOD, J., COMER,C., MCCAFFREY, M.S., BUHR, S.M., **GOLD, A.U.**, LYNDS,S.E., MANDUCA, C.A., FOX, S., KIRK, K., IVERSON, E., NIEPOLD, F., HOWELL, C., CARLEY, S. (2010): Climate Literacy and Energy Awareness Network (CLEAN) Pathway - Teaching Climate and Energy Science: Teaching materials, Professional Development, Social Networking. National Science Digital Libaray (NSDL) Annual Meeting, Washington, D.C. (November 2010).

BUHR, S.M., ARTHUR, T., **GOLD, A.U.**, LYNDS, S.E., MCCAFFREY, M.S., SMITH, L., WISE, S. (2010): Highlights from the CIRES Education and Outreach Group. CIRES Rendez-Vous (April 2010)

REUTHER, A., IVY-OCHS, S., FIEBIG, M., KUBIK, P.W. & HEINE, K. (2007): Dating the LGM: attempts from the type-region of the Würmian glaciation in the southern German Alpine Foreland and from the Central German Highlands INQUA 2007 - 17th International Congress of the Union of Quaternary Research (Jul/Aug 2007).

HEINE, K., **REUTHER, A.U.**, URDEA, P., IVY-OCHS, S., KUBIK, P.W., GEIGER, C., SCHLAAK, N. & NILLER, H.-P. (2007): Timing of Late Pleistocene mountain glaciation using cosmogenic in situ ^{10}Be: the southern Carpathians and the Bavarian Forest compared to the Bavarian Alpine Foreland and northern Germany. - 17th International Congress of the Union of Quaternary Research (Jul/Aug 2007).

URDEA, P., **REUTHER, A.**, HEINE, K., IVY-OCHS, S., KUBIK, P.W. & GEIGER, C. (2007): New data concerning

Quaternary glaciation in the Transylvanian Alps (Romania). - 17th International Congress of the Union of Quaternary Research (Jul/Aug 2007).

REITNER, J. M., **REUTHER, A. U.**, IVY-OCHS, S., HERBST, P., STADLER, H., KUBIK, P. W. & DRAXLER, I., (2006): The sturzstrom event of Feld (Matrei/Eastern Tyrol/Austria): A forgotten catastrophe during early human settlement in the Alps? 150 Years of Neanderthal Discoveries: Early europeans - continuity & discontinuity Conference, Bonn, Germany (Jul 2006).

REUTHER, A.U., REITNER, J., IVY-OCHS, S. & HERBST, P. (2006): From kinematics to dating – the sturzstrom deposits of Feld (Matrei, Eastern Tyrol, Austria). European Geoscience Union (EGU) Conference, Vienna, Austria (Apr 2006).

FÖRSTER, K., **REUTHER, A.U.**, FIEBIG, M.C., STRUNK, H. & HEINE, K. (2006): Dating of raised beach deposits in Gipsdalen, coastal west Svalbard, using surface exposure dating (^{10}Be, ^{36}Cl) and radiocarbon ages. European Geoscience Union (EGU) Conference, Vienna, Austria (Apr 2006).

FÖRSTER, K., **REUTHER, A.U.**, FIEBIG, M.C., STRUNK, H. & HEINE, K. (2006): Dating of raised beach deposits in Gipsdalen, coastal west Svalbard, using surface exposure and radiocarbon ages. Atlantic Geoscience Society (AGS) Conference, Wolfville, Nova Scotia, Canada (Feb 2006).

GEIGER, C., **REUTHER, A. U.**, URDEA, P. & HEINE, K. (2004): GIS-basierte Modellierung der Gletschergleichgewichtslinie (ELA) des Spätglazials im Valle Pietrele, Retezat Gebirge, Südkarpaten. Arbeitskreis (AK) für Geomorphologie Conference, Heidelberg, Germany (Oct 2004).

REUTHER, A.U., GOSSE, J.C., IVY-OCHS, S., FIEBIG, M.C., KUBIK, P.W., YANG, G. & HEINE, K. (2004): Dating of the LGM: Attempts from the type-region of the Wuermian in the South German Alpine Foreland and from the Central German Highlands. International Geological Congress (IGC) Florence, Italy (Aug 2004).

Current and Pending Support for Anne U. Gold

Support: Current

Project/Proposal Title: Collaborative Research: Confronting the Challenges of Climate Literacy

Source of Support: NSF DRK12

Total Award Amount: $ 21, 2357

Total Award Period Covered: 9/1/10-8/31/14

Location of Project: TERC, Cambridge, MA / Boulder, CO

Person-Months Per Year Committed to the Project: 2 y2; 3.5 y3; 1.9 y4

Support: Current

Project/Proposal Title: Lens on Climate Change in Colorado

Source of Support: CU Outreach Office, CIRES

Total Award Amount: $13,100

Total Award Period Covered: 8/1/13-5/31/14

Location of Project: Boulder, CO

Person-Months Per Year Committed to the Project: 1 month

Support: Current

Support: Current

Project/Proposal Title: Surface Energy Budgets at Arctic Terrestrial Sites: Quantifying Energy and Momentum Fluxes and their Associated Physical Processes

Source of Support: NSF

Total Award Amount: $24,013

Total Award Period Covered: 7/1/11 - 6/30/14

Location of Project: Boulder, CO

Person-Months Per Year Committed to the Project: 0.73 month

Support: Current

Project/Proposal Title: ClimateGov Evaluation

Source of Support: NOAA

Total Award Amount: $ 79,907

Total Award Period Covered: 7/15/13-5/31/14

Location of Project: Boulder, CO

Person-Months Per Year Committed to the Project: 2.37 months

Support: Current

Project/Proposal Title: Climate Literacy and Energy Awareness Network (CLEAN) Core Activities

Source of Support: NOAA

Total Award Amount: $ 392,884

Total Award Period Covered: 1/1/14-12/31/16

Location of Project: Boulder, CO

Person-Months Per Year Committed to the Project: 3 m Yr 1, 9 m year 2,3

Support: Pending

Project/Proposal Title: CAREER: BREEZE: Boundary-. layer REsearch and Education ZonE
Source of Support: NSF CAREER

Source of Support: NSF

Total Award Amount: $561,133

Total Award Period Covered: 07/01/14 – 06/30/18

Location of Project: Boulder, CO

Person-Months Per Year Committed to the Project: 1.2 months per year

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Support: Pending

Project/Proposal Title: Collaborative Research: Effective Teaching of Earth and Climate Science Through the Next Generation Science Standards (NGSS)
Source of Support: NSF

Total Award Amount: $142,008

Total Award Period Covered: 9/1/14-8/31/18

Location of Project: Boulder, CO

Person-Months Per Year Committed to the Project: 1.2 months per year