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SEDucate: Sedimentary Log Exercises for an Active Learning Environment*

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Abstract

Active learning in education has been shown to improve a students' learning experience in higher education by focusing on a student-centered learning environment; however, development of realistic activities that replicate the complexity of real-world examples without being too complex for the novice learner is often challenging. Here we present SEDucate, a GIS plugin to build realistic active-learning exercises in sedimentology course curriculums by creating unique sedimentary logs for a tailored assessment based on modern sedimentary environments. The automated creation of simple sedimentary logs for a variety of different depositional environments can be implemented in a wide range of exercises and assessments as either individual or group-based work. SEDucate allows for the teaching on the characterization of sedimentary logs, interpretation of paleogeographic environments and the lateral variation observed in modern sedimentary environments.

Keywords: sedimentary logs, modern depositional environments, active learning, education

1. Introduction

For students to get the best possible learning experience, it is generally agreed that there needs to be 'constructive alignment' between the material being taught (the 'learning outcomes'), how the material is taught and how it is assessed (e.g., Biggs, 1996). In particular, if the teaching material is of a practical nature, such as interpreting sedimentary logs, then both the teaching method and assessment should be adapted to that. Thus, instead of teaching using traditional lectures, a teacher-centered approach, it is better to use active learning techniques in the classroom, i.e., a student-centered approach. Similarly, the assessment should be closely related to the material used in class.

Many studies on active learning, including active learning in the STEM disciplines at the university level, have been conducted. These studies strongly suggest that active learning improves students' acquisition of concepts (e.g., Freeman et al., 2014, Deslauriers et al., 2019). Therefore, in the context of constructive alignment, active learning has been promoted for many years at many universities, including the geosciences (e.g., Manduca et al., 2017). However, recent studies also suggest that teaching centered techniques (e.g., lectures) still remains the most common method in many STEM disciplines (Budd et al., 2013; Teasdale, 2017; Stains et al., 2018).

There are a number of reasons that active learning methods are not used, including unfamiliarity with active learning, fear that active learning is not appreciated by students (e.g., Henderson, 2018), institutional barriers (Henderson, 2013), lack of training, and lack of teaching material (Lukes, 2014; Deslauriers et al., 2019; Laursen, 2019). It is quite understandable that in many cases there is a lack of such teaching material as it is quite time consuming to modify existing exercise sets or replace these completely. While for each STEM discipline the challenges are different, as the type of work and exercises involved are different (Reinholz, 2019), there clearly is a need for a practical way to develop a large number of relevant problems that can be used in both teaching and assessment.

Several institutions and websites are dedicated to education in the geosciences. These include the Science Education Resource Center (SERC), Centre for Integrated Earth Science Education (iEarth), Science Teaching Hub and Seds Online to name a few. Within these valuable resources, several sedimentology specific teaching material are available, which are focused on teaching students' how to interpret sedimentary deposits, sedimentary processes, and depositional environments. However, the complexity of real-world field examples often makes it difficult to introduce fundamental principles for novice geology students. In sedimentology, few teaching resources exist of sedimentary log exercises that are suitable for an entry-level course curriculum (Bristow, 2020). A need for the development of interpretable sedimentary log exercises, that may also show the lateral variability observed in modern sedimentary systems exists. Furthermore, it is important to supplement existing resources to have a wide range of active-learning material since studies on teaching methods show this positively improves student performance (Freeman et al., 2014, Deslauriers et al., 2019).

In this paper, we present a method and framework to create student-centered sedimentary log exercises for introductory sedimentology courses. We describe the method and show how sedimentary logs are created for many different types of depositional environments and how to use this material in for various classroom settings and assessments.

2. Material and Methods

Teaching and assessing the fundamentals in sedimentology requires theoretical and practical experience creating sedimentary logs, characterizing sedimentary successions into facies and facies associations, and interpreting the paleogeography of past environments. Here we introduce a tool, called SEDucate, for creating sedimentary logs and paleogeography exercises based on modern depositional environments that students may use to make observations and interpret the paleogeography.

SEDucate is an open-source QGIS plugin used to construct sedimentary logs based on examples of modern depositional environments, Figure 1. The repository, installation, and an initial set of resources and accompanying user guide to demonstrate the potential of the approach for an active-learning resource in sedimentology course curriculums is available in the data availability section.

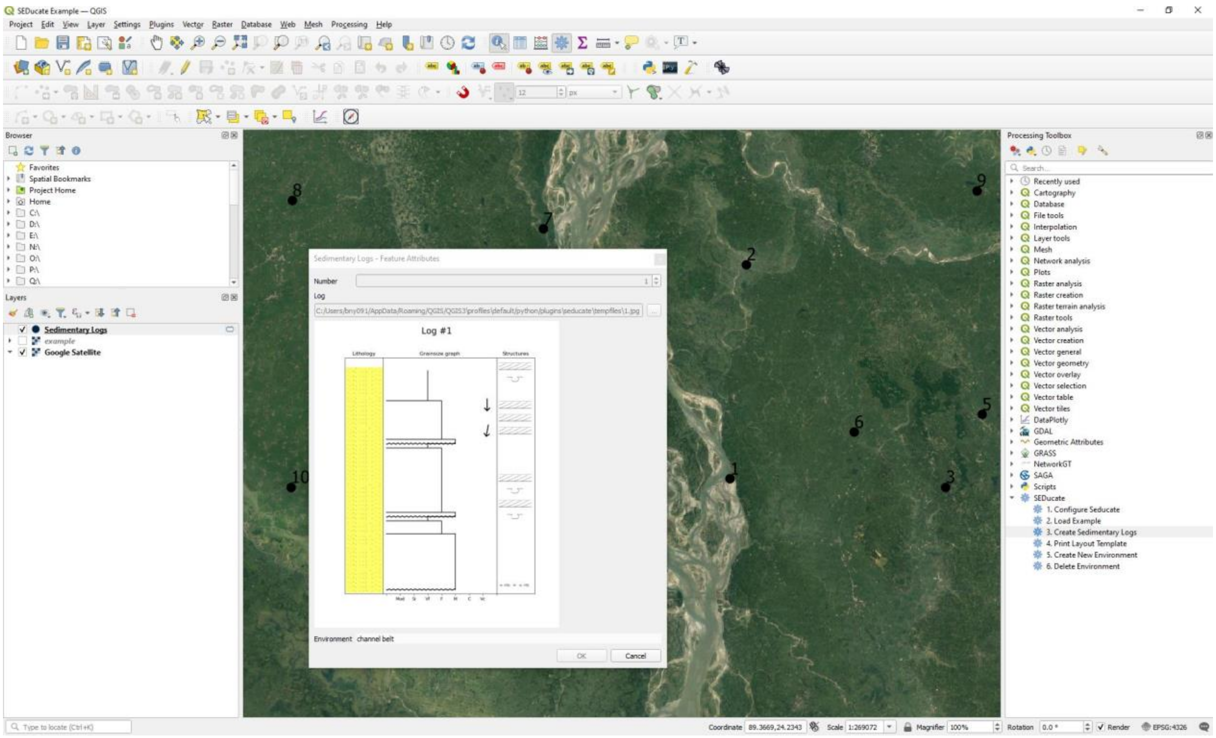

Figure 1 SEDucate Plugin - Example of the interactive QGIS interface and the SEDucate toolbox for creating sedimentary log exercises.

2.1. Sedimentary Log Profile

The nature of interpreting depositional environment(s), which is based on characterizing sedimentary layers into units of facies and facies associations provides an opportunity to create tailored sedimentary log exercises. This is achieved by automatically creating a sedimentary log based on the knowledge that facies, facies associations or depositional environments will occur next to one another based on Walther’s law (Walther, 1894). By varying the vertical sequence of facies, facies associations or depositional environments, a unique sedimentary log is created that will vary vertically in observations.

The creation of each facies, facies associations or depositional environments is based on predefined profiles produced as vector graphs within the Python scripting language (Figure 2). The profile is defined by the algorithm by specifying the starting grainsize, a maximum grainsize, a minimum grainsize and its thickness over that interval. Optionally, a trend to the grainsize profile may be selected as either coarsening upwards or fining upwards. Lastly, the contact at the base of each profile is defined as either sharp or erosional. Sedimentary structures corresponding to the depositional environment are subsequently added to each log section by relating the environment and grainsize to the different types of structures. The algorithm will automatically create an idealized sedimentary log that honor the constrains dictated by the profile while varying the observed sedimentary structures.

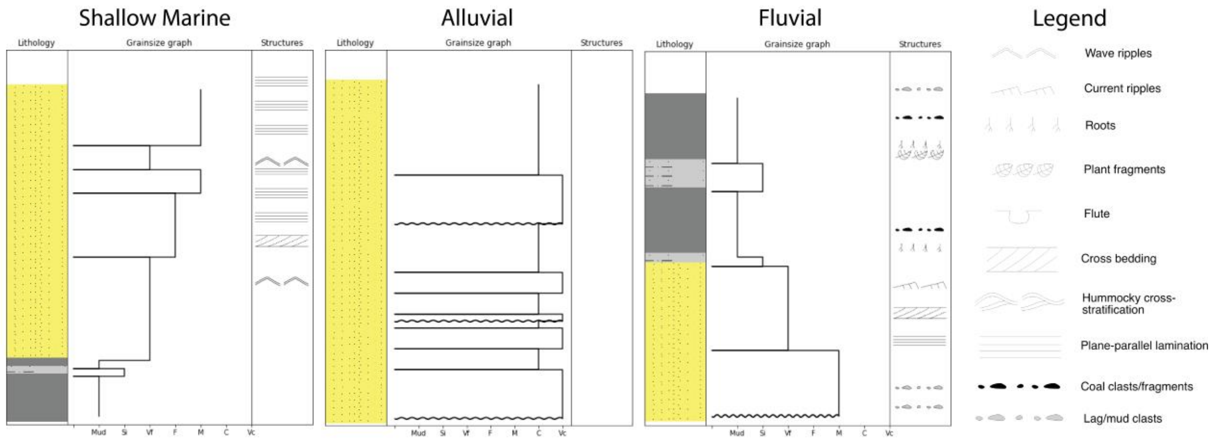

Figure 2 Sedimentary Log Profiles – Example sedimentary log profiles for shallow marine, alluvial and fluvial settings. Note the fluvial profile shows a combined channel belt and floodplain signature.

In the initial version of SEDucate, sedimentary log profiles are available for 8 different depositional environments and sub-environments including: alluvial fan, channel belt, floodplain, eolian, lacustrine, shallow marine, turbidite and deep marine settings (Table 1). The SEDucate interface does allow for the creations of additional sedimentary log profiles that may be used to increase the number of environments or profile detail by defining the parameters mentioned above. Further information on the creation of new sedimentary environments is available in the User Guide on our GitHub page that is provided in the data availability section.

Table 1 Sedimentary Log Profiles - Sedimentary log profiles available by the SEDucate plugin, the parameters used and the corresponding raster code for each environment. Start, Min and Max refer to the grainsize profile from 1 (mud) to 7 (very coarse). FU – fining upwards, CU – coarsening upwards

Environment	Code	Start	Min	Max	Thickness	Trend	Contact
alluvial fan	0	7	5	7	3	FU	erosional
channel belt	1	5	3	5	3	FU	erosional
floodplain	2	1	1	3	3	0	sharp
lacustrine	4	2	2	4	3	0	sharp
eolian	5	4	4	5	3	0	sharp
shoreface	6	3	3	4	3	CU	sharp
deep marine	9	1	1	1	3	0	sharp
turbidite	10	1	1	3	3	0	erosional
nodata	11	0	0	0	3	0	none

2.2 Sedimentary Log Creation

The creation of a sedimentary log based on a modern depositional environment is achieved by relating a map location to a sedimentary log profile. This requires a rasterized map of a modern depositional environment (or conceptualized paleogeography) with a code for each pixel (Figure 3A) that corresponds to the sedimentary profiles listed in Table 1. The algorithm will sample the raster at each sedimentary log location to create a sedimentary log profile as previously described in section 2.1. Furthermore, digital elevation models may supplement the depositional environment map to include paleocurrent measures on the sedimentary log creation that may be relevant in, for example, fluvial environments.

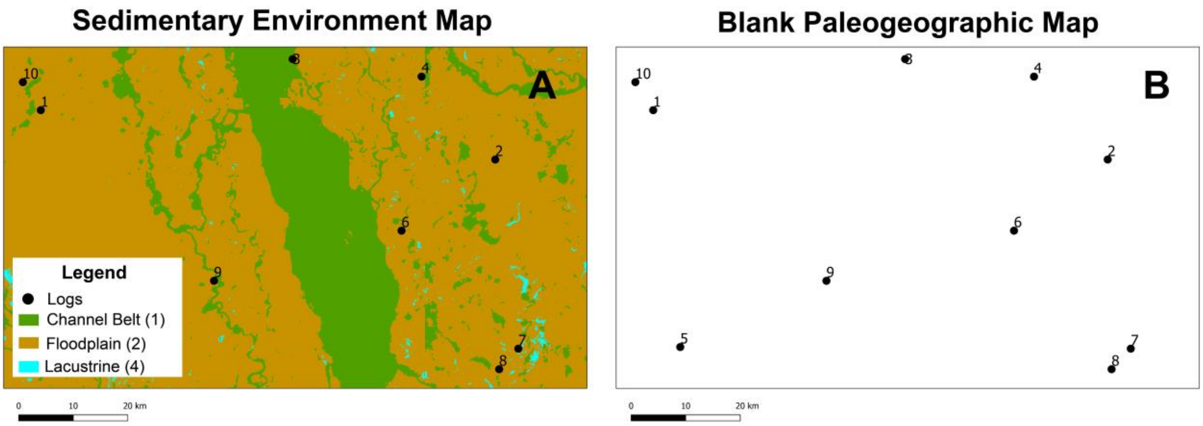

Figure 3 - A) A simplified sedimentary environment map showing the distribution of floodplains and channel belts from the Brahmaputra, Bangladesh in Figure 1. Random locations for the sedimentary logs are numbered 1 to 10. B) An uninterpreted map that students may use to interpret the paleogeography based on the sedimentary logs created at each location. The number of sedimentary logs provided to the students can be chosen and added sequentially to improve previous interpretations. See main text for more detail.

Currently, SEDucate requires a rasterized map to be manually defined prior to the creation of sedimentary logs. A few examples are provided within the SEDucate plugin. However, this may also provide an opportunity to teach students fundamental concepts in GIS within a context of sedimentology by allowing them to first create a depositional environment map for another student to interpret (see section 3.1). Furthermore, with the increasing accuracy and level of detail in global scale classifications including the Dynamic World (Brown et al., 2022) and the Global River Morphology (GRM) map (Nyberg et al., 2022), it is hoped that the SEDucate will soon provide a range of different sedimentary environments for students to explore globally.

The locations of the sedimentary logs can be chosen manually or randomly within the extent of the depositional environment map (Figure 4). In the field, it is common practice to describe multiple sedimentary logs from an outcrop or core to interpret the vertical and lateral variability to best constrain the likely paleogeography. In a similar manner, the creation of the simplified sedimentary logs by the SEDucate plugin to describe a modern depositional environment may be used to illustrate the lateral variability that exists in the modern depositional environment.

2.3 Vertical Variation

Optionally, a probability matrix may be used to create variation in the vertical succession of a sedimentary log. This is achieved by sampling the depositional environments that surround a given sedimentary log locality by a user-specified search radius. Based on the number and category of pixels defined within each search radius, a probability matrix is created that will inform the algorithm of the next sedimentary log profile to select in a vertical succession (Figure 4). The number of sedimentary log profiles to select is also user-specified. This allows for subtle variations in the vertical trend of a sedimentary log to show the shorter timescale variability that may arise laterally across a sedimentary environment.

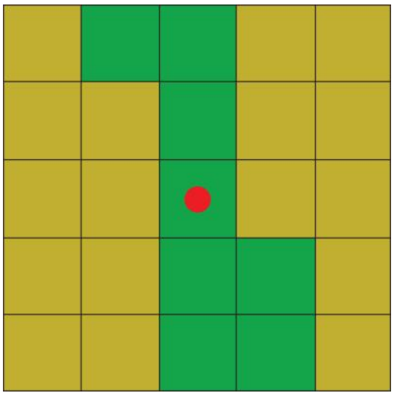

Figure 4 Probability Matrix – A probability matrix may be used to relate the probability that a sedimentary log may be represented by one or more depositional environments in a vertical succession. In this example, 8 grid cells are defined as a channel belt (green) or a 32% probability and 17 grid cells are defined as floodplain (brown) or a 68% probability. The red dot shows the location of the sedimentary log.

As an example, the first environment selected from a sedimentary environments map (e.g., Figure 3) is defined as a channel belt. The algorithm will first select a sedimentary profile of a channel belt and subsequently define a probability matrix. The probability matrix may state that next trend in the vertical succession has a 32% chance of defining another channel belt and a 68% chance of a floodplain environment (Figure 4). The algorithm will continue to populate the sedimentary log with additional sedimentary log profiles until the user-specified number of iterations is reached. This may create the variation in an amalgamated channel belt character in Figure 1 versus the channel belt and floodplain character in Figure 2.

2.4 Limitations

It should also be noted that the vertical variability in sedimentary logs is not intended to show longer term transgressions or regressions. If this is desired, multiple depositional environments maps should be created with each one representing a different point in time. Furthermore, SEDucate does not currently map variation in thickness along dip or strike. However, given the sedimentary profiles are vector graph representations based on the parameters listed in Table 1 that include thickness, this may be implemented in future versions of SEDucate. This would require an additional raster dataset to be created showing the trends in thickness across the basin but would also allow for additional exercises to be created related to isopach reconstructions.

3. Results and Discussion

The additional resources presented in this manuscript are best suited towards the end of an introductory sedimentology course curriculum once the fundamental concepts of facies, facies associations, depositional environments and sedimentary log creation have been taught. The exercises are ideal for the teaching of the most important concepts in interpreting depositional environments and paleogeography from log observations before applying those methods and knowledge in the field. The material can be implemented in existing course curriculums, either in-class or online, in an active learning environment or as a method to create individualized assessments for a constructive alignment between the material being taught and examined.

3.1 Active Learning Approach

SEDucate and the proposed teaching material can complement existing sedimentology course curricula by providing an additional active-learning resource that is suitable for either individual or group-based work. By providing uninterpreted sedimentary logs, students can learn how to describe facies and facies associations from simple idealized logs before introducing additional complexity. The sedimentary log descriptions then aid in interpreting different depositional environments which can easily be understood by relating the results to satellite observations of the modern example.

If implemented in groups, the exercise provides a chance for students to discuss amongst their peers to reach a consensus on different scenarios and plausible interpretations. Successively including additional sedimentary logs to the same exercise (e.g., 5 to 10 logs in Figure 3B) is a great method to show how additional data helps to constrain the paleogeography and to reinterpret their previous conclusions. Alternatively, multiple but shorter exercises, each containing fewer sedimentary logs to interpret, can be designed for several different depositional environments. This gives the students more feedback in an interactive approach between each exercise, thus providing positive feedbackto the students. Given the sedimentary logs are automatically created, both approaches are feasible and has the further advantage of providing an active learning experience. As both McConnell et al. (2003) and Johnson and Reynolds (2005) have noted, the use of self-drawn geological sketches such as those created by paleogeographic reconstructions, is an excellent active-learning technique to engage student participation and deeper level thinking.

The paleogeographic map to be reconstructed by the student can be based on a simple conceptualized illustration, a previously interpreted paleogeography from the field or literature, or a modern depositional environment (e.g., Figure 3A). If a sedimentary field excursion is planned in the course curriculum, this is a good opportunity to design the exercise with similar depositional environments that will be defined in the field for a constructive alignment approach (e.g., Biggs, 1996). We recommend separating the exercises between characterising sedimentary logs and interpreting depositional environments/paleogeography to allow students to receive feedback before applying sedimentary log interpretations to define a paleogeography. Another option is to utilise the opportunity to teach students fundamental concepts in Geographical Information Systems (GIS) by first creating an exercise whereby students, working alone or in groups, define the map to be interpreted by another student or group. Examples of these exercises are available in the supplementary material provided on our GitHub page.

3.2 Assessment Techniques

The automated method for creating sedimentary logs using SEDucate can be used to define a tailored exam for each student while reducing the time-consuming nature to develop, create and assess material for sedimentology courses. Given the description of facies, facies associations, depositional environments and resulting paleogeographic map are previously known, the efficiency in evaluating the work will be significantly improved for the educator. The learning outcomes of the unique sedimentary logs and random location within the theoretical sedimentary system will test a students ability to make observations and correlate between sedimentary logs to define a paleogeography. Furthermore, the exam questions can be tied to previous exercises in the course but for different depositional environments and sedimentary logs thus connecting the material taught and assessed.

An individual assessment can provide a unique set of sedimentary logs for each candidate to characterize or a paleogeography to interpret with questions applicable to any depositional environment or sedimentary log. Typical tasks may include for example:

1. Divide and describe the sedimentary logs into its units of facies and facies associations (Figure 2).
2. Characterize the depositional environments based on the interpreted facies associations.
3. Sketch the paleogeography of the interpreted depositional environments (e.g., Figure 3B).

In the assessment of student performance that provides a fair, timely and efficient evaluation and prevents unwarranted results is challenging, especially in an unproctored environment. A properly administered online exam, however, can reduce unwarranted results by using; i) a synchronous exam, ii) a time limit, iii) random order of questions and multiple choice answers, iv) a pool of question combinations, v) viewing limited number of questions at any given time, vi) use of a restricted web browser and vii) no back-tracing (Cluskey Jr., et al., 2011). While the implementation of the preventative measures helps to mitigate cheating, it may not be suitable for all forms of assessment. In the sedimentological studies, a large portion of the assessment is related to the deeper-level thinking associated with interpreting depositional environments from sedimentary logs. The creation of individualized assessments for in person classes and online courses by the SEDucate approach provides an ability to assess performance in an unproctored environment without reservations regarding result integrity.

4. Conclusions

The current manuscript proposes a method to create sedimentary logs for a constructive alignment between the material taught and assessed in introductory sedimentology course curriculums. These logs represent a simplified rendition of realistic stratigraphy while still capturing some of the stratigraphic complexity, making the exercise developed using this tool appropriate for the novice stratigraphy learner. By using the repetitive nature of facies and facies associations observed in the stratigraphic record, automated sedimentary logs can be created to generate tailored sedimentary log exercises. We have shown a framework and created a plugin SEDucate to show how such an approach may be used to efficiently create and implement tailored sedimentary logs for an active-learning experience. The flexibility in generating sedimentary logs for a wide-range of depositional environments can be used as individual or group-based exercises and assessments for a variety of teaching methods, classroom settings and/or learning outcomes. The proposed methods and resources should supplement other active-learning approaches in the classroom to best engage, motivate and promote critical thinking of the fundamental principles in sedimentology.

Data Availability Statement: The SEDucate plugin is available for download within the QGIS plugin manager. The source code, installation instructions and user guide are available at github.com/BjornNyberg/SEDucate/wiki.

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References

Biggs, J., 1996. Enhancing teaching through constructive alignment. *Higher education*, *32*(3), pp.347-364.

Budd, D.A., Van der Hoeven Kraft, K.J., McConnell, D.A. and Vislova, T., 2013. Characterizing teaching in introductory geology courses: Measuring classroom practices. *Journal of Geoscience Education*, *61*(4), pp.461-475.

Bristow, C.S., 2020. A virtual graphic log for clastic sediments. *Sedimentary Geology*, *405*, p.105703.

Brown, C. F., Brumby, S. P., Guzder-Williams, B., Birch, T., Hyde, S. B., Mazzariello, J., Czerwinski, W., Pasquarella, V. J., Haertel, R., Ilyushchenko, S., Schwehr, K., Weisse, M., Stolle, F., Hanson, C., Guinan, O., Moore, R., & Tait, A. M. (2022). Dynamic World, Near real-time global 10 m land use land cover mapping. *Scientific Data*, *9*(1), 251.

Cluskey Jr, G.R., Ehlen, C.R. and Raiborn, M.H., 2011. Thwarting online exam cheating without proctor supervision. *Journal of Academic and Business Ethics*, *4*(1).

Deslauriers, L., McCarty, L.S., Miller, K., Callaghan, K. and Kestin, G., 2019. Measuring actual learning versus feeling of learning in response to being actively engaged in the classroom. *Proceedings of the National Academy of Sciences*, *116*(39), pp.19251-19257.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, *111*(23), 8410–8415.

Henderson Hurley, M. and Hurley, D., 2013. Enhancing Critical Thinking Skills among Authoritarian Students. *International Journal of Teaching and Learning in Higher Education*, *25*(2), pp.248-261.

Johnson, J.K. and Reynolds, S.J., 2005. Concept sketches—Using student-and instructor-generated, annotated sketches for learning, teaching, and assessment in geology courses. *Journal of Geoscience Education*, *53*(1), pp.85-95.

Laursen, S.L. and Rasmussen, C., 2019. I on the prize: Inquiry approaches in undergraduate mathematics. *International Journal of Research in Undergraduate Mathematics Education*, *5*(1), pp.129-146.

Lukes, L.A. and McConnell, D.A., 2014. What motivates introductory geology students to study for an exam?. *Journal of Geoscience Education*, *62*(4), pp.725-735.

Manduca, C.A., Iverson, E.R., Luxenberg, M., Macdonald, R.H., McConnell, D.A., Mogk, D.W. and Tewksbury, B.J., 2017. Improving undergraduate STEM education: The efficacy of discipline-based professional development. *Science Advances*, *3*(2), p.e1600193.

McConnell, D.A., Steer, D.N., Owens, K.D., Knott, J.R., Van Horn, S., Borowski, W., Dick, J., Foos, A., Malone, M., McGrew, H. and Greer, L., 2006. Using conceptests to assess and improve student conceptual understanding in introductory geoscience courses. *Journal of Geoscience Education*, *54*(1), pp.61-68.

Nyberg, B., Henstra, G., Gawthorpe, R., Ravnås, R., Ahokas, J., 2022. Planetary Scale Analysis of the Morphology of River Channels and Channel Belt Deposits. Eartharxiv Prepr. https://doi.org/10.31223/X5Q066

Reinholz, D.L., Matz, R.L., Cole, R. and Apkarian, N., 2019. STEM Is Not a Monolith: A Preliminary Analysis of Variations in STEM Disciplinary Cultures and Implications for Change.

Stains, M., Harshman, J., Barker, M.K., Chasteen, S.V., Cole, R., DeChenne-Peters, S.E., Eagan, M.K., Esson, J.M., Knight, J.K., Laski, F.A. and Levis-Fitzgerald, M., 2018. Anatomy of STEM teaching in North American universities. *Science*, *359*(6383), pp.1468-1470.

Teasdale, R., Viskupic, K., Bartley, J.K., McConnell, D., Manduca, C., Bruckner, M., Farthing, D. and Iverson, E., 2017. A multidimensional assessment of reformed teaching practice in geoscience classrooms. *Geosphere*, *13*(2), pp.608-627.