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Modeling And Conceptual Representations Work Together In The Undergraduate Classroom

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***Abstract*— Models are central to science education practice. To implement model based learning in the science classroom, however, instructors often rely on external lessons that are often not designed for their classroom. We suggest a 3 principle approach that can be positioned on current competency-based instruction. We conclude with ideas for assessment and implications.**

Keywords—education, modeling, environmental engineering.

INTRODUCTION

“Scientific models can be useful for someone who doesn’t know much about the subject to learn in an easy way, they also can be used to collect data, understand the results, and share with others the research.”

-College Junior, Midwestern University, Natural Resources Class

Modeling has been noted as critical elements for scientific practice (see multiple studies from kindergarten through life e.g., Chrysafiadi and Virvou 2014). With these studies, arguments have been made as to how classroom instructors can adopt specific classroom model-based teaching practices (e.g., Jordan et al. 2014). What is missing, however, is strategies for how faculty can create model-based learning experiences beyond a particular individual lesson and instead, use modeling as common practice to promote competency not only in classes but throughout curricula; especially in higher education.

For this paper, we define models as simplified abstractions that can represent scientific phenomenon (Crawford and Jordan 2013, Gilbert 1993, Jordan et al. 2017). Such representations enable testing of ideas, for example, through simulation or as hypotheses related to how the world works. Models can be physical replica, written, mathematical, or entirely conceptual. In instruction, model construction and revision in its simplest form is a process of posing and modifying explanations that helps students to understand the underlying mechanisms around particular phenomena. Models can exist as hypotheses, conjectures, or as explanations for complex ideas. Models can also serve as tools for communication and for assessment.

Models are powerful learning tools because they help learners cognitively offload complex ideas (See review in Morrison and Richmond 2020). Learners are afforded the opportunity to look at links or relationships between elements within their model for which we, as the scientific community, have more or less evidence. In this way, the model allows students to put ideas to test and they can further refine with additional evidence. This refining process also encourages students to look both at the context their model is situated in and to abstract scenarios around ideas or phenomenon they are modeling. In doing so, they are mirroring a compare or contrast cognitive operation, which has also been shown to result in large learning gains for students (e.g., Marzano 1991) and can foster transfer of learning (Jordan et al. 2013), which is essential for developing competency.

While there are multiple ways that educators can use models in the classroom to support complex thinking, it appears that educators often employ models as a way to directly communicate static knowledge (Treagust et al. 2002, Van Driel and Verloop 1999). We argue that this predominant conception of a scientific model as a static tool can limit the ways that students view complex systems as being dynamic. In addition, when models are used as static representations, students lack the opportunity to predict or reason around that system or phenomenon (Carey and Smith 1993, Van Driel and Verloop 1999).

We suggest that a lack of design principles to support educators trying to engage undergraduates in developing models may limit model use throughout a course and instead support the one-off use of certain modeling tools. Such limitation will likely hinder competent development of skills. In the course of having students develop models throughout our courses, we have found that certain principles guide our instruction. During discussions of our teaching practices we pared these to three predominant principles. Below we discuss these principles (also see Table 1) and provide examples of how these are enacted. Following the discussion of our approach, we discuss assessment and provide concluding thoughts.

Table 1: Principles for instructors to use models in the absence of specific modeling lesson plans.

3 principles	Questions to ask	Example
Conceptual representation	What questions should the learner ask themselves to help them approach the content in a generalizable manner?	SBF PMC-2E 5 Es†
Unstructured to structured	How can you elicit what the learner currently knows, and what is the scaffold or pathway that the learner could take to develop their ideas?	Progression from rich pictures, to concept mapping, to fuzzy cognitive maps, to scenario building
Interrogation and refinement	When and how should learners receive and give feedback on the models and in what ways are learners able to modify their models to accommodate new knowledge?	Using a process where students us models to take notes, then they engage in peer-review, followed by collaborative development of models and instructor feedback. Finally requiring that written explanations have a model as support or vice versa.

†Table footnote: the 5 E instructional model is from Vigeant, F. (2017) What is the 5E instructional model? Blog accessed on 2/28/2020: https://www.knowatom.com/blog/what-is-the-5e-instructional-model#:~:text=

A. *Our approach: 3 Principles*

1. Move from unstructured to structured

We argue that it is necessary to scaffold learning experiences so that learners can develop their scientific practices with reducing teacher support as the semester continues. In the context of models, this means working from where the learners are and talking them through the epistemic process to move them from relatively unstructured models to those that have greater structure and internal consistency. With this, we have found that the models will move toward greater sophistication over the course (Jordan et al. 2017, Sorensen et al. in revision).

By starting with an unstructured space, the educator can build on a students' (versus the instructors') prior knowledge versus starting from the point of the instructor. Per the executive summary in the National Research Council's "How People Learn" (NRC 1999), working from students' preconceived notions is essential to aiding learners to make connections. Many believe that it is only from shaping conceptions that true learning happens (e.g., Nersessian 2006) and we argue this cannot happen unless all learners are able to make what they are thinking visible.

As an example of an unstructured space, we have found that having students sketch out ideas in a format (e.g., rich pictures, which are symbols, icons, etc.) of their choice to diagram a system or theory of change can help them communicate ideas along a continuum where they can progressively add more structure to their ideas. For example, students can begin to identify causal agents and linkages. From there, the instructor or group members can work to add more detail, with precision, and perhaps more accuracy.

Following something like rich pictures, students can progressively add more details and even apply rules. For example, the learners could use stock and flow models or concept maps where choice of representation and labels is limited. These rules or guidelines will allow individuals to mentally put their models to test by asking, "What would happen if I change this or that?" Such questions could allow students the opportunity to determine outcomes of teacher directed scenarios. Then as students begin to move from their naïve conceptions to a narrower band of instructor guided conception, the instructor can give different contexts to see how the model and student ideas are able to address change. Instructors can also work with these guided approaches to help the learner move along qualitative to quantitative continua. In our work, we have moved from descriptive concept-map type models (Jordan et al. 2014) to semi-quantitative type models (Gray et al. 2013).

2. Give them conceptual representations

As we move students from their desired and independent depictions of their understanding to models that are more structured and bound by rules, we argue that providing them with mental supports will ease this transition and enable them to better transfer ideas. A conceptual representation is a cognitive framework that helps a learner organize their ideas. Conceptual representations can help students to organize how they need to think about particular ideas alongside what to think about these ideas. We work with our students to engage with conceptual representations through a metaphor of the filing system on their computer. These learners not only work with individual files when they are building ideas in the classroom but these ideas are being organized in an often non-linear but hierarchical web. Akin to cognitive resources (Hammer 1994) or knowledge in pieces (DiSessa 1993), complex ideas are integrated closely with other ideas such that an appropriate tag (or file folder label) can often help students to access a wealth of resources behind or within that cognitive space. Important to this approach is ensuring that the instructor model their thinking by speaking the ideas and questions aloud; akin to a cognitive apprentice model (Brown and Collins 1991).

The conceptual representations that we have used, for example, involve the learner asking questions of a particular pattern or process that they notice in nature. These questions begin by having learners ask themselves what phenomena they are being asked to explain first. After this they are told to ask what generic mechanisms have they learned about this conceptual area in the past. Finally, we ask them what parts of the system are involved and what is the evidence they have to support their ideas or explanations (Jordan et al. 2014). To support asking these questions we have used an evolution of the SBF (structure-behavior-function) conceptual representation (Eberbach et al. 2021, Liu and Hmelo-Silver 2009), called PMC-2E (an acronym for Phenomena, Mechanism, Components, Evidence, and Explanation) representation to help support students reason about mechanisms in complex systems (Jordan et al. 2014). First the questions are placed where students can constantly access them and by the end of the semester all that is necessary to cue these questions that students ask themselves is the acronym PMC-2E. When a student is struggling, the instructor only need to point to it to help cue the learner.

We also argue that conceptual representations can help students to transfer ideas from one learning context to the next. Individuals who are able to create generic mechanisms to explain particular phenomena about which they are learning, may be able to apply those mechanisms in different contexts. This is not possible if the idea is context specific. In addition, if we think about learning transfer similar to that of Bransford and Schwartz' (1999) preparation for future learning, students will be prepared based on previous learning to re-learn ideas. In this way the learner views something in a novel context as being relevant to a previous context and then knows what types of questions to ask to understand the novel context.

3. Allow room for interrogation and refinement

Finally, we feel it essential to guide students not only through the process of making ideas visible for others to see but they must also learn to interrogate and refine ideas. To do so, it is essential that that learners themselves have the opportunity to revisit models as concepts and ideas develop throughout the course. This can also help the learners connect evidence to their models which is essential to teaching the practices of how we know what we know in science (Pluta et al. 2008). Too often when one element of a course is completed students are not afforded the opportunity to revisit or refine with new knowledge. We therefore argue that spiraling back to original ideas and allowing the learners to see what is different and what is similar to what they learned earlier in the course will help to deepen their newly conceived ideas versus reverting back to their naïve conceptions. We have found that if we use multiple perspectives and different types of pictures and graphics to represent ideas, students can better link cognitive ideas to externally visualized ideas (akin to Hsu 2006).

Assessment and Class Size

While we are still gathering data to support this, we have found using model-based assessments have enabled us the opportunity to ask students to represent ideas that are dynamic and non-linear. We have found this to be a particularly important for system level phenomena such as changing climate in a particular location where the learner also needs to manage outcomes at different scales. Doing so on the part of the learner can be difficult in an essay or narrative where one sentence follows another in a linear fashion. Models can serve as graphic organizers that conveys visual information quickly (e.g., Hall and Strangman 2002, Mede 2010). Through modeling, instructors along with their learners, can determine the extent to which learning goals are being met with quick inspection. We have also found that early and often feedback in a formative sense can provide more summative success (Jordan and Sorensen unpublished data).

CONCLUSION

When we share our views to other science educators especially in higher education, they point out a major barrier to model based instruction is class size. With a large class (e.g., 50+), are model based assessments too difficult to grade? Most recently we have begun to investigate how models can be used in large courses to help students track course materials, solve complex problems, and to support explanations and arguments. In particular, have been working with class sizes over 100 students. We have been using a process of self and peer assessment, collaborative modeling, and spaced-over time assessments (e.g., only a portion of students turn in their assignments at any given time). We have also been working to track instructor time devoted to assessment. Our preliminary data suggest that student models can be quickly typified, which resulted in an uneven (e.g., earlier models make take more time but later models move very quickly) but relatively equal amount of assessment time as grading multiple objective and short essay type examinations. So while initial inspection of models takes longer than subsequent models, when you move to guiding their models with the conceptual representations and or specific rules, the same representation and rules can be used to create rubrics to assess learning (akin to Jordan et al. 2014). Our initial results are similar to others that when models are integrated as part and parcel of the instruction, it is possible to integrate these into large lecture courses (e.g., Dauer et al. 2013).

While we are early in our examination of model-based instruction in larger classes, we believe that there is sufficient supporting evidence to suggest that using the broad practices of modeling juxtaposed on course content can help students manage the multiple and dynamic layers of complex scientific ideas and systems. Additionally, with software support, we were able to combine different tools to ensure students had a series of modes in which they needed to think about and make ideas visible throughout the course. We also found that by teaching and assessing using the same tools, we were not only efficient but also more aligned with the course learning goals, which include not only abstract conceptions but also competent skill development. We conclude with the suggestion that more instructors try to iteratively implement model-based learning in the classroom without the use of specific lessons that are often designed for other courses.

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REFERENCES

Bransford, J.D., Schwartz, D.L. (1999). Rethinking transfer: A simple proposal with multiple implications (Vol. 24). Washington DC: American Educational Research Association.

Carey, S., and Smith, C. (1993). On understanding the nature of scientific knowledge. Educational psychologist, 28(3), 235-251.

Chrysafiadi, K., and Virvou, M. (2013). Student modeling approaches: A literature review for the last decade. Expert Systems with Applications, 40(11), 4715-4729.

Clement, J. (2000). Model based learning as a key research area for science education. International Journal of Science Education, 22(9), 1041-1053.

Crawford, B., and Jordan, R. (2013). Inquiry, models, and complex reasoning to transform learning in environmental education. Trading zones in environmental education: creating transdisciplinary dialogue. Peter Lang, New York, New York, USA, 105-123.

Dauer, J.T., Momsen, J.L., Bray-Speth, E., Makohon-Moore, S., Long, T.M. (2013). Analysis of student-constructed models of complex biological systems. Journal of Research on Science Teaching 50, 639–659.

DiSessa, A. A. (1993). Toward an epistemology of physics. Cognition and instruction, 10(2-3), 105-225.

Gilbert, J.K. (1993). Models and Modeling in Science Education. UK: Association for Science Education.

Gray, S. A., Gray, S., Cox, L. J., and Henly-Shepard, S. (2013, January). Mental modeler: a fuzzy-logic cognitive mapping modeling tool for adaptive environmental management. In 2013 46th Hawaii International Conference on System Sciences (pp. 965-973). IEEE.

Hall, T., and Strangman, N. (2008). Graphic organizers: A report or the National Center on Assessing the General Curriculum at the Center for Applied Special Technology. Portland, ME: Walch Education.

Hammer, D. (1994). Epistemological beliefs in introductory physics. Cognition and Instruction, 12(2), 151-183.

Eberbach, C., Hmelo-Silver, C. E., Jordan, R., Taylor, J., & Hunter, R. (2021). Multidimensional trajectories for understanding ecosystems. Science Education, 105(3), 521-540.

Hsu, Y. S. (2006). ‘Lesson Rainbow’: the use of multiple representations in an Internet- based, discipline- integrated science lesson. British journal of educational technology, 37(4), 539-557.

Jordan, R. C., Gray, S. A., Brooks, W. R., Honwad, S., and Hmelo-Silver, C. E. (2013). Process- Based Thinking in Ecosystem Education. Natural Sciences Education, 42(1), 68-74.

Jordan, R. C., Sorensen, A. E., and Hmelo-Silver, C. (2014). A conceptual representation to support ecological systems learning. Natural Sciences Education, 43(1), 141-146.

Jordan, R. C., Gray, S., Sorensen, A. E., Pasewark, S., Sinha, S., and Hmelo-Silver, C. E. (2017). Modeling with a Conceptual representation: is it necessary? does it Work?. Frontiers in ICT, 4(7).

Liu, L., and Hmelo- Silver, C. E. (2009). Promoting complex systems learning through the use of conceptual representations in hypermedia. Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 46(9), 1023-1040.

Marzano, R. J. (1991). Fostering thinking across the curriculum through knowledge restructuring. Journal of Reading, 34(7), 518-525.

Mede, E. (2010). The effects of instruction of graphic organizers in terms of students’ attitudes towards reading in English. Procedia-Social and Behavioral Sciences, 2(2), 322-325.

Morrison, A. B., and Richmond, L. L. (2020). Offloading items from memory: individual differences in cognitive offloading in a short-term memory task. Cognitive Research: Principles and Implications, 5(1), 1.

Nersessian, N. J. (2006). The cognitive-cultural systems of the research laboratory. Organization Studies, 27(1), 125-145.

National Research Council. (1999). How people learn: Bridging research and practice. National Academies Press.

Pluta, W. J., Buckland, L. A., Chinn, C. A., Duncan, R. G., and Duschl, R. A. (2008, June). Learning to evaluate scientific models. In Proceedings of the 8th international conference on International conference for the learning sciences-Volume 3 (pp. 411-412).

Rosenblueth, A., and Wiener, N. (1945). The role of models in science. Philosophy of science, 12(4), 316-321.

Sorensen, A.E., Alred, A., Fontaine, J.J., Dauer, J.M. In Revision. A model-based instructional approach in a course-based undergraduate research experience (CURE).

Treagust, D. F., Chittleborough, G., and Mamiala, T. L. (2002). Students' understanding of the role of scientific models in learning science. International Journal of Science Education, 24(4), 357-368.

Van Driel, J. H., and Verloop, N. (1999). Teachers' knowledge of models and modelling in science. International Journal of Science Education, 21(11), 1141-1153.