Appendix 1-1 Profiles of experience learners

	Leo	Cathy	Dave	Mike	Charles
Sex	Male	Female	Male	Male	Male
School	SNRE	SNRE	SNRE	SNRE	SPH
Year in school	5th year	5th year	3rd year	4th year	3rd year
Subject specialty	PhD student in Resource Policy & Behavior; Master degree in computer science. Works in GIS lab;	PhD student in water resources Just finished her dissertation	PhD student, Wetland restoration and mitigation consulting in a firm; river systems; water level fluctuation and water source in wetlands in southeastern Michigan.	PhD student, streamside riparian wetlands and their role in river ecosystems; Generally familiar with aspects of river ecosystems and their influence on water quality, Taught basic water chemistry to graduate and undergraduate students.	PhD student in Environment Health Science Master of public health Water quality management.
Modeling experience	Taught how to use STELLA for living.	Diagram models from her dissertation obtained	Used modeling programs: ArcView; ArcInfo GIS; and HEC **(**http://www.dodson-hydro.com/**)**.	Created GIS-based models in publications.	Modeling drinking water distribution systems; Computer applications, modeling and computer-assisted real time data acquisition and control methods.

Note: SNRE--School of Natural Resources and Environment;
SPH--School of Public Health;
GIS--Geographic Information System;
ArcView--method of look at digital map
HEC--Hydro Engineer C.

Appendix 1-2 Profiles of novice learners: 7th grade science students during school year 99-00 Water quality unit I

Student pair	LM & EB Lisa (G) Elena (G)	DA & PA Don (B) Pat (B)	AC & CD Alan (B) Carla (G)	AT & RN Arno (B) Rose (G)	RF & AW Ron (B) Abby (G)	KN & WR Katy (G) Wyne (B)
Class period	B	B	C	C	D	D
Teacher	Alice	Alice	Carol	Carol	Jack	Jack
Characteristic of this pair	The are both average students and equally contributed to their model	Don seemed to proposed more ideas than Pat. Both are average students.	Both are above average students. Cathy contributed more ideas.	Rose is an average student, while Arno is a little bit below average. Both contribute equally.	Both are about average. Abby contributed more than Ron.	Both students are above average. Katy made more suggestions while Wyne's ideas were more accepted.

Note: G = Girl; B = Boy

Appendix 1-3 Profiles of novice learners: 7th grade science students during school year 99-00 Decomposition Unit

Student pair	GM & KV George (B) Ken (B)	AS & BJ Alex (B) Ben (B)	AT & LP Arno (B) Laura (G)	AS & RN Ash (B) Rose (G)	RF & AW Ron (B) Abby (G)	KN & WR Katy (G) Wyne (B)
Class period	B	B	C	C	D	D
Teacher	Alice	Alice	Carol	Carol	Jack	Jack
Characteristic of this pair	George is below average while Ken is a better student. Ken made most the decisions.	Both are active and average students. Equally contributed to their model.	Laura is about average. Arno proposed most ideas while Laura critiqued more.	Ash was similar to Arno. Both contribute equally.	Both are about average. Abby contributed more than Ron	Both students are above average. Katy made more suggestions while Wyne's ideas were more accepted.

Note: G = Girl; B = Boy

Appendix 2 Coding scheme for modeling practices

	Modeling practices are scientific practices in modeling. They are actions and conversations that reflect students' reasoning processes.
4.1 Planning	Planning include statements or actions in which students identify important components of phenomena they are going to model; decide relationships, patterns that variables are going to be connected, or in which they attempt to predict on their model's behavior.
4.1.1 Generating ideas	Students talk about what they are going to model, e.g. I am going to model the water quality in the stream behind our school; I am going to model the decomposition of daily garbage of my house.
4.1.2 Stating goals	Students decide what their driving question and sub-questions, e.g. how clean is the stream in my community; does street runoff affects the water quality of the stream? Students articulate what kind of model they should have, e.g. I want a simple model; I want the model to be as complex as I can to include all the factors that I have.
4.1.3 Identifying factors/objects	Students specify an entity as an object or a factor without further discussion or explanation. For example, "Let's have more animals", "We need a factory in our model".
4.1.4 Specifying relationships	Students talk about between what factors they need to create relationships and what the relationship should look like. For example, one student suggested "I think we need build relationship between the amount of cars and water quality because cars bring salt from the bridge into Huron River. It should be "more and more" because the more cars run across the bridge the more salt is brought into the water."
4.1.5 Discussing factors/objects	Students talk about/share ideas on the meanings of objects/factors, fill in description boxes; discuss what objects/factors are relevant (or not relevant) to their driving questions or modeling goals; they discuss factors' initial values.
4.2 Searching	Searching includes talking and actions of getting more inputs in terms of any questions students have when they are creating models.
4.2.1 Seeking information	Students ask either their teacher or their peers for answer of content knowledge, or modeling ideas. For example, a student asks "do you know how to delete a factor?", or "how can I change the initial value?"
4.2.2 Gathering resources	Students check their note, search online resources or go to library to gain more information about their project and model.
4.3 Synthesizing	Synthesizing are statements or actions related to viewing the content, behavior, or form of a model as a whole, or to making connections between previously unconnected ideas.
4.3.1 Discussing relationships	Students discuss correlation or cause and effect relationships. For example, one pair of students decided to delete the relationship between biological contaminants and ground water quality because there are not so many biological contaminants in ground water.
4.3.2 Making connections	Students make explanation or argument with the support from their experience or what they have learned, e.g. we did not find pH value change too much from 7 in our investigation so that it is not the major factor that affects water quality.
4.4 Analyzing	Analyzing involves students' statements or actions to decompose the large system that they are going to model into sub-systems or components. The purpose is selecting the appropriate objects, factors and relationships to reflect the most important characteristics of the model. It may also involve students' meta-cognition or reflective behavior so that they can decide what they should do next.
4.4.1 Deciding about course of action	Students state what they are going to do next, e.g. "let's go to build mode because we have already had enough factors". "Let's add a factor on animal population"
4.4.2 Recognizing the need of test	Students state their need for test so that they can analyze the model's behavior in test model. For example, Student says "The model is too complex, let's test it now". "I want to see how factory emission affects water quality."
4.5 Explaining	Explaining is associated with students' talking or writing to show others about their ideas and the reasons of their thinking.
4.5.1 Explaining	Students explain relationship between factors; make cause and effect statements. For

why/how	example, Students say “As acid rain increases water quality decreases more and more because acid rain contain pollutants” “It’s more and more because acid rain can be disastrous to plants, animal, building as well as people while it increases to some degree”.
4.5.2 Justifying arguments	Students try to make a logical argument to support an idea or explanation. They may either give examples or state evidence.
4.5.3 Elaborating ideas	Students restate an idea, demonstrate it to others. For example, One student say that he want to use “liquid effluent’ to replace “factory waste” because liquid waste is the main pollutant source in his “water quality model”.
4.6 Evaluating	Students talk about the quality of their model; present their model to others to get feedback or test the model in order to improve their model.
4.6.1 Predicting what should happen	Students say things like “it should do…when we run it” or “it’s going to…”; or, they say “it did not do what I thought it should do”.
4.6.2 Identifying anomalies	Students have some unexpected findings. For example, one student found that they could not change the slide bar in the meter of dependent variable. Another student found that when acid rain increases water quality did not change that much as he predicted. A third student found that the colorful graph line of one factor does not show up because this one’s initial value was set the same as another factor’s. A fourth student found that when they run their model nothing happened.
4.6.3 Critiquing/interpreting the results	Students make comments on the test results when they run their models, such as “when turbidity goes high water quality goes down…” “it’s working…” “…something is wrong her…”
4.6.4 Identifying/proposing solutions	Students suggest ways to correct anomalies. “I know, X goes down because we have the relationship going the wrong way”.
4.6.5 Carrying out solutions	Students actually do their proposed solution. For example, students create a stream quality factor after the teacher point out that is something they missed in their water quality model. This generally occurs after students propose solutions. (not all changes get this code)
4.7 Other	Used only for interesting items, no code covers.

Appendix 3

Table 4-1 The frequency of modeling practices during novice students' "Water quality" modeling processes

	Plan Mode		**Build Mode**		**Test Model**	
Name	Number of Instances		Number of Instances		Number of Instances	
LM & EB	26		21		19	
	1(4 1 2)	1(4 2 2)	3(4 1 3)	3(4 3 1)	1(4 1 2)	1(4 5 1)
	8(4 1 3)	4(4 4 1)	2(4 1 4)	5(4 4 1)	1(4 1 5)	2(4 5 3)
	7(4 1 5)	2(4 5 1)	2(4 1 5)	3(4 5 3)	4(4 2 1)	5(4 6 3)
	2(4 2 1)	1(4 5 3)	2(4 2 1)	1(4 6 5)	4(4 4 1)	1(4 6 4)
DA & PA	11		29		10	
	1(4 1 1)	1(4 4 1)	1(4 1 1)	3(4 3 2)	2(4 1 5)	1(4 5 3)
	5(4 1 3)	1(4 5 1)	8(4 1 4)	4(4 4 1)	1(4 4 1)	1(4 6 2)
	3(4 1 5)		3(4 1 5)	1(4 4 2)	2(4 5 1)	2(4 6 3)
			1(4 2 1)	3(4 5 1)		1(4 6 4)
			2(4 3 1)	3(4 6 5)		
AC & CD	18		11		17	
	2(4 1 1)	1(4 3 1)	1(4 1 5)	1(4 4 2)	5(4 6 2)	5(4 6 4)
	4(4 1 3)	1(4 3 2)	1(4 2 2)	2(4 5 1)	7(4 6 3)	
	2(4 1 5)	3(4 4 1)	3(4 3 1)	2(4 6 5)		
		5(4 5 1)	1(4 3 2)			
AT & RN	12		21		20	
	2(4 1 1)	2(4 2 1)	1(4 1 3)	2(4 4 1)	1(4 1 5)	1(4 5 3)
	5(4 1 3)	1(4 4 1)	1(4 1 4)	2(4 4 2)	3(4 2 1)	3(4 6 2)
	1(4 1 5)	1(4 5 1)	5(4 2 1)	7(4 5 1)	1(4 4 1)	6(4 6 3)
			3(4 3 1)		4(4 5 1)	1(4 6 4)
RF & AW	13		11		17	
	2(4 1 3)	3(4 4 1)	1(4 1 1)	2(4 3 1)	1(4 1 5)	2(4 4 1)
	1(4 1 5)	2(4 5 1)	1(4 1 2)	1(4 4 1)	1(4 2 1)	2(4 5 1)
	2(4 2 1)	2(4 5 3)	1(4 1 5)	4(4 5 1)	1(4 3 1)	2(4 6 1)
			1(4 2 1)		2(4 3 2)	2(4 6 2)
						4(4 6 3)
KN & WR	16		32		32	
	1(4 1 2)	1(4 4 1)	2(4 1 4)	7(4 4 1)	2(4 1 5)	4(4 6 2)
	2(4 1 3)	1(4 5 3)	2(4 1 5)	1(4 5 1)	2(4 2 1)	8(4 6 3)
	9(4 1 5)	1(4 6 4)	1(4 2 1)	3(4 5 3)	1(4 3 1)	6(4 6 4)
	1(4 2 1)		15(4 3 1)	1(4 6 4)	3(4 3 2)	2(4 6 5)
					3(4 4 1)	
					1(4 5 3)	
Summary	**95**		**116**		103	
	5(4 1 1)	1(4 3 1)	**2**(4 1 1)	**28**(4 3 1)	7(4 1 5)	5(4 5 3)
	2(4 1 2)	1(4 3 2)	1(4 1 2)	4(4 3 2)	**10**(4 2 1))	**10**(4 6 2)
	26(4 1 3)	**13**(4 4 1)	4(4 1 3)	**19**(4 4 1)	2(4 3 1)	**32(**4 6 3)
	23(4 1 5)	**11**(4 5 1)	**15**(4 1 4)	3(4 4 2)	8(4 4 1)	**14**(4 6 4)
	7(4 21)	4(4 5 3)	9(4 1 5)	**17**(4 5 1)	9(4 5 1)	2(4 6 5)
	1(4 2 2)	1(4 6 4)	10(4 2 1)	6(4 5 3)		
			1(4 2 2)	1(4 6 4)		
				6(4 6 5)		
Note:	RF&AW was absent on day 2. On day 3, only AT&RN, KN&WR had some activity in plan mode;		RF&AW was absent on day 2. On day 3, AC&CD did not engage n any modeling practices		On Day 1, LM&EB did not have test mode activity; RF&AW was absent on day 2. On day 3, AC&CD did not engage n any modeling practices	

Total instances of each practice

40(4 4 1): Decide course of action
39(4 1 5): Discussing fac/obj
37(4 5 1): Explain why/h.
32(4 6 3) Crit.&Interp. Resul.
32(4 1 3): Identifying object/factor
31(4 3 1): Discu. Relation
27(4 2 1): Seek info.
16(4 6 4) Iden./Prop. Solutions
15(4 5 3) Elab. Ideas
15(4 1 4) Specifying relationships
10(4 6 2) Iden. Anomalies
8(4 6 5) Carrying out solutions
7(4 1 1): Generate ideas
5(4 3 2) Making connection
3(4 1 2) Stating goals
2(4 2 2) Gathering resoucrces

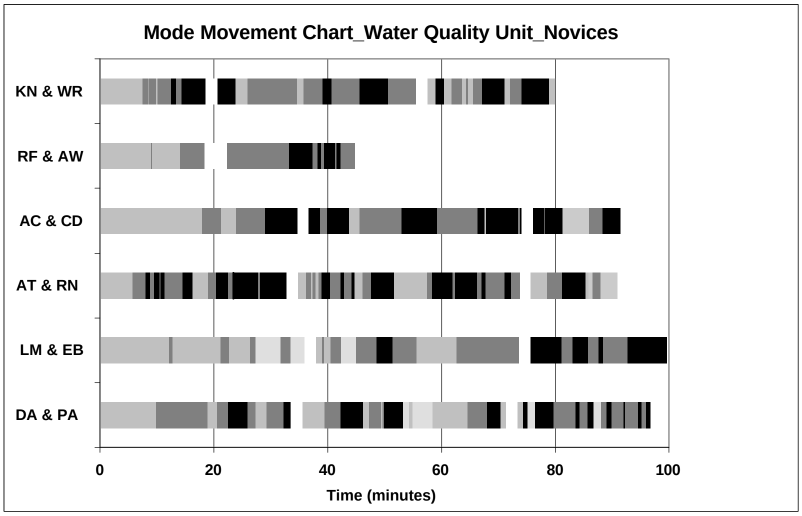
Table 4-2 The frequency of modeling practices during PhD students' "Water quality" modeling processes

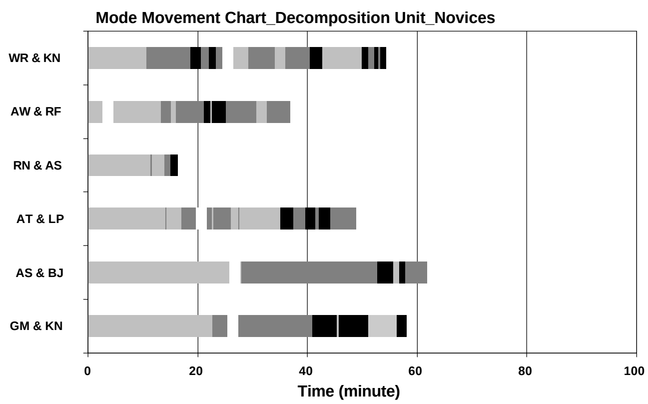
	Plan Mode		**Build Mode**		**Test Model**	
Name	Number of Instances		Number of Instances		Number of Instances	
Leo	20		18		7	
	1(4 1 1)	3(4 2 1)	1(4 1 1)	2(4 4 1)	2(4 2 1)	1(4 6 4)
	1(4 1 2)	1(4 4 1)	2(4 1 2)	1(4 5 1)	2(4 6 2)	1(4 8 4)
	7(4 1 5)	7(4 5 1)	2(4 1 5)	1(4 8 1)	2(4 6 3)	
			7(4 3 1)	2(4 8 4)		
Cathy	13		18		4	
	1(4 1 2)	4(4 5 1)	3(4 1 2)	5(4 3 1)	1(4 2 1)	
	4(4 1 5)	3(4 8 1)	3(4 1 5)	3(4 5 1)	2(4 6 3)	
	1(4 3 1)		3(4 2 1)	1(4 8 1)	1(4 8 4)	
Dave	17		17		15	
	1(4 1 1)	5(4 3 1)	3(4 1 5)	1(4 4 1)	1(4 1 3)	4(4 6 2)
	1(4 1 3)	5(4 5 1)	3(4 2 1)	5(4 5 1)	2(4 2 1)	2(4 6 3)
	5(4 1 5)		5(4 3 1		2(4 3 1)	3(4 6 4)
					1(4 4 1)	
Mike	27		16		14	
	1(4 1 1)	4(4 2 1)	2(4 2 1)	4(4 8 1)	1(4 1 2)	3(4 6 2)
	2(4 1 2)	8(4 5 1)	2(4 3 1)	1(4 8 4)	1(4 2 1)	5(4 6 3)
	4(4 1 3)	3(4 8 1)	1(4 4 1)		2(4 4 1)	2(4 6 4)
	3(4 1 5)	2(4 8 4)	6(4 5 1)			
Charles	28		11		7	
	2(4 1 1)	2(4 2 1)	1(4 1 1)	2(4 3 1)	1(4 1 1)	1(4 6 2)
	1(4 1 2)	10(4 5 1)	1(4 1 2)	1(4 4 1)	1(4 2 1)	1(4 6 3)
	3(4 1 3)	2(4 8 4)	1(4 1 5)	4(4 5 1)	2(4 4 1)	1(4 6 4)
	8(4 1 5)		1(4 2 1)			
Summary	**104**		**69**		**47**	
	5(4 1 1)	6(4 3 1)	**2**(4 1 1)	21(4 3 1)	1(4 1 1)	5(4 4 1)
	5(4 1 2)	1(4 4 1)	6(4 1 2)	13(4 5 1)	1(4 1 2)	10(4 6 2)
	7(4 1 3)	**34**(4 5 1)	9(4 1 5)	6(4 8 1)	1(4 1 3)	12(4 6 3)
	27(4 1 5)	6(4 8 1)	9(4 2 1)	3(4 8 4)	6(4 2 1)	7(4 6 4)
	9(4 2 1)	4(4 8 4)			2(4 3 1)	2(4 8 4)
Note						

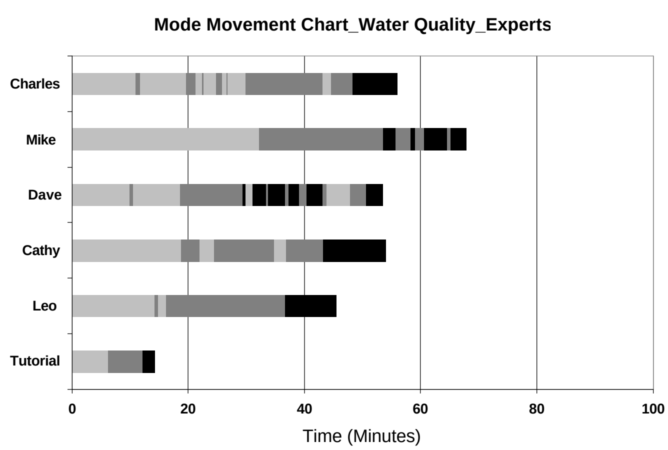
Total instances of each practice

47(4 5 1): Explain why/h.
36(4 1 5): Discussing fac/obj
29(4 3 1): Discu. Relation
24(4 2 1): Seek info.
12(4 1 2) Stating goals
12(4 6 3) Crit.&Interp. Resul.
12(4 8 1) Refer phenomena
11(4 1 2) Stating Goals
10(4 6 2) Iden. Anomalies
9(4 8 4) Refer literature
8(4 1 1): Generate ideas
8(4 1 3): Identifying object/factor
7(4 6 4) Iden./Prop. solutions
6(4 4 1): Decide course of action
4(4 7 1) Exploring
3(4 5 3) Elab. Ideas

Appendix 5 Mode movement charts







Plan mode **Build mode** **Test mode** **Mode separator**

Technical problem **Shifting** **Off-task**

Appendix 6 Detailed frequency of mode movement

Table 5-1 Novices water quality unit

Name	Plan	Build	Test	Shift-ing	Tech. Problem	Off-task	Total	Note
WR&KN	10	12	8	1	0	0	**32/32**	
RF&AW	2	6	4	0	0	0	**13/13**	Missed 2nd day
AC&CD	3	7	9	1	0	3	**20/23**	*
AT&RN	11	20	17	2	0	2	**40/42**	
LM&EB	6	12	5	0	3	0	**23/26**	
DA&PA	10	13	13	0	4	0	**36/40**	

Table 5-2 Novices decomposition unit

Name	Plan	Build	Test	Shift-ing	Tech. Problem	Off-task	Total	Note
WR&KN	3	8	6	0	0	0	**17/17**	
RF&AW	4	5	2	0	0	0	**11/11**	
RN&AS	2	2	1	0	0	0	**5/5**	Missed 2nd day
AT&LP	5	8	3	0	0	0	**16/16**	
AS&BJ	2	3	2	0	0	0	**7/7**	
GM&KN	2	2	3	0	1	0	**7/8**	

Table 5-3 Expert water quality

Experts WQ	Plan	Buil d	Test	Shift-ing	Tech. Problem	Off-task	Total	Note
Chris	7	6	1	1	0	0	**15/15**	Not used to utility
Matt	1	4	4	0	0	0	**9/9**	
David	4	6	5	1	0	0	**16/16**	More build&test for trouble-shooting utility
Christine	3	3	1	0	1	0	**7/8**	She lost her model at the end
Luis	2	2	1	0	0	0	**5/5**	He is very familiar w/ STELLA

***** Since technical problems and off-tasks were not modeling activities, the occurrence(s) was not counted. For example, 20/23 means students were on task 20 out of 23 moves.

Appendix 7 Model layouts analysis

Note: For technical reason, the powerpoint file was not included in this paper. Please contact the first author if you are interested in the file (**Email:** bhzhang@umich.edu)