Proceedings of the Eighteenth Annual Meeting of the

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Mathematics, Science and Technology – Crossing the boundaries

Improving the quality of Science, Mathematics and technology education through relevant research and a continued multi- and inter- disciplinary approach to teaching.

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Volume 2 : Short Papers

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Vygotsky, L. S. (1978). *Mind in Society: The Development of Higher Psychological Process*. Cambridge: Harvard University Press.

Exploring Students' Interpretation of Electric Fields around Molecules Using a Haptic Virtual Model: An Evolving Study

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Surprisingly, very little empirical work has explored the application of students' knowledge about electric fields to a chemistry context. In response, this paper reports a pilot study that investigated students' conceptions about electric fields, and how interaction with a haptic virtual model impacts understanding of electric fields around molecules. Students first responded to specially-designed written free response items that probed knowledge transfer. The participants then interacted with the model while performing think-aloud tasks where different haptic modes offered by the model were activated. Qualitative induction of the data revealed that although students demonstrated a pronounced and classical understanding of electrostatic forces and electric fields, they struggled to apply this knowledge to a molecular context. Interestingly, there was a strong association between the existence of an electric field around a molecule with the notion of chemical polarity. Analysis of videotaped interaction with the model provided evidence for distinct influences on students' understanding, which included using the model to gain unique insight into the nature of electric fields, and as a sensory tool for actively challenging existing alternative conceptions. Future work will expand the research framework presented here and also distil what specific perceptual experiences are related to any changes in knowledge.

Introduction

Surrounding any stationary charged object is an electric field that exerts a force on any charged particle placed within the field. Although electric field is an important idea in school Physics, students find the concept difficult. Students often assign a 'matter-based' understanding to electric field lines, and struggle to connect electric field properties with the corresponding force exerted on a charged particle (e.g., Furió & Guisasola, 1998; Pocoví, 2007). Törnkvist, Petterson, and Tranströmer (1993) have shown that students understand field lines as isolated entities rather than as curves representing electric field vector properties. In this regard, dynamic learning environments may actively induce students to adjust such existing conceptions. For example, Dede, Salzman, Loftin, and Ash (2000) have shown increases in students' conceptual understanding after interacting with a virtual model that stimulated a visual comparison of electric force with potential through a dipole representation that depicted accompanying field lines and test charge traces.

We suggest that the concept of electric field is also vital for understanding molecular interactions since all intermolecular forces are essentially *electrostatic* in nature. Molecular electrostatic properties are also intertwined with concepts of chemical polarity, molecular shape and reactivity. Specifically, any distribution of charge will give rise to an electric field. Often, such distributions are represented by a set of point charges, which together, constitutes a multipole. It follows that monopoles (e.g., Na^+, Cl^-), dipoles (e.g., H_2O, O_3) and quadrupoles (e.g., CO_2, N_2) all exhibit a corresponding electric field. Hence, the majority of molecules are *always* associated with an electric field, including molecules that exhibit a dipole moment (i.e. 'polar') *as well as* those that do not (i.e. 'nonpolar').

Surprisingly, delving into *whether* and *how* students merge their 'physical' understanding of electric fields with their 'chemical' understanding about molecules remains uncharted. It is this junction that is the genesis of this research, where we employed a unique haptic virtual model to explore students' understanding of electric fields around molecules. A further motivation for the study is that although tactile feedback can help students develop accurate concepts of force fields (e.g., Reiner, 1999), little is known about the pedagogical merits of haptic virtual systems in Science education (Minogue & Jones, 2006). Moreover, we are yet to come across any haptic virtual model that has been used as an educational tool for visualising electric fields emanating from molecules.

Description of the Haptic Virtual Model

A bimodal (visual and tactile) virtual model developed by Lundin Palmerius, Cooper, and Ynnerman (2008) was used to investigate students' understanding of electric fields around molecules. A default 'ball-and-stick' representation is visually rendered to depict a molecule (a van der Waals surface can also be activated), while a stereoscopic display provides a 3D perception of the molecule that can be rotated using a 3D mouse. Interaction with the electric field is achieved by delivering force feedback to the user through a haptic device, where a corresponding visually rendered stylus is used to move a 'probe' relative to the molecule (Figure 1).

Two different haptic modes are available for interaction with the electric field. In a *force* mode, the probe is exposed to the force aligned with the electric field at the accompanying probe point. The probe corresponds to a positive test charge, and therefore, the perceived force is in the direction of the electric field. In a *force and follow* mode, an identical force as that described for the force mode is experienced in the direction of the field, but whenever the probe is moved in a direction not aligned with the electric field an opposing force is applied. Although this second force component serves to constrain the movement of the probe in the direction of the field line, the opposing force is weak enough to allow movement of the probe in other directions. The perceptual effect of the opposing force is to convey the feeling of moving the probe through a viscous medium.

Overall, the *force* mode is a representation of the force that would be applied to a positive test charge in the electric field. In the *force and follow* mode, the force feedback serves to impart a sense of the 'shape' and direction of the electric field. The electric field can also be represented visually by rendering field lines upon pushing a button on the haptic device. Each subsequently generated field line is displayed as a narrow blue 'tube' that intersects the probe point (see Figure 3).

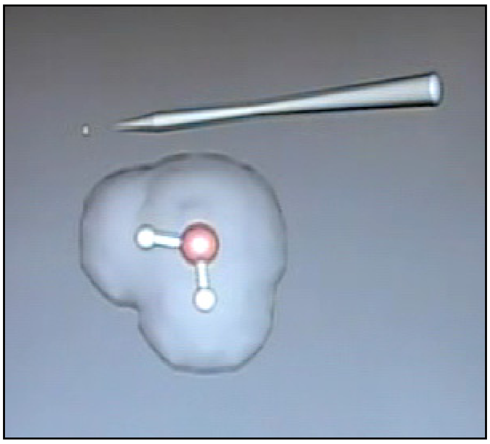

Figure 1. Video screenshot from a monitor displaying an H_2O molecule in 'ball-and-stick' and van der Waals surface format together with the stylus and probe (small white sphere).

Aim and Research Questions

The overall aim of this study was to investigate the influence of a haptic virtual model on students' understanding of electric fields around molecules. Specifically, we posed the following research questions:

i) What are students' conceptions about electric fields, and how are these applied to a molecular context?

ii) How does interacting with the model influence understanding of electric fields around molecules?

To date, we have responded to these questions in the form of a pilot study from which the methods employed and subsequent preliminary results are reported in this paper. We are presently evolving the research agenda defined herein.

Methods

Participants and data-collection instruments

An explorative paradigm was utilised to gather and treat data (e.g., Erickson, 1986). Five 11^{th} and 12^{th} Grade volunteers (designated 'S1' through 'S5') enrolled in a Natural Science program at a Swedish secondary school participated in the study. To investigate conceptual knowledge before interaction with the model, participants provided written responses and student-generated diagrams (SGDs) to six probes concerned with electric fields and electrostatic forces. Three examples of the probes were as follows:

1. What is an electric field? Use diagrams to support your answer.

2. Consider the following diagram showing two point charges. Draw the electric field in the diagram. Fully motivate your answer.

3. Consider the following 'ball-and-stick' diagrams of an H_2O and a CO_2 molecule that show partially positively and negatively charged atoms. Fully describe why, or why not, there is an electric field associated with (or surrounding) these molecules. Support your answer by using drawings in each of the diagrams.

Other than elucidating students' knowledge about electric fields and electrostatic forces, we also explored whether students could transfer 'classical' Physics-related knowledge about electric fields to a chemistry context. Thus, as depicted above, the probes were ordered in a less-to-more cognitively demanding direction, with each probe requiring an increased degree of knowledge transfer (e.g., Schönborn & Bögeholz, 2009).

Following the written test, four of the five students participated in semi-structured clinical interviews. Students interacted with the model and completed a series of tasks while various haptic modes were activated at different points. Two of the tasks that each student performed whilst the *force* and *force and follow* modes were engaged, respectively, were as follows:

4. On the screen there is an H_2O molecule depicted in 3D ball-and-stick format. The H_2O molecule has a region that is partially positively charged, and a region that is partially negatively charged. Consider that the small white ball at the tip of the pen is a positive point charge. Interact with the haptic model to describe and deduce the position of the positively and negatively charged regions of the molecule.

5. A CO_2 molecule is shown on the screen. Imagine that you are positioned at the tip of the pen. Generate field lines around the molecule [by pushing the button on the stylus]. Select one [generated] stream tube and use the haptic device to follow that trajectory. Fully explain the relationship between what you see and what you feel and how this is related to the properties of the molecule.

During the interviews, students were stimulated to 'think-aloud' while interacting with the model. All interviews were audio and video recorded. A dual monitor that outputted students' movement of the stylus and virtual molecule was also videotaped (see Figure 3). Verbal interviewer-student exchanges were transcribed and the text pegged to the video.

Data Analysis

Data analysed in this study consisted of written responses, SGDs and videos of students' interaction with the model. Data analysis proceeded qualitatively by induction (Glaser & Strauss, 1967) wherein themes in the data were elucidated according to the following steps, not necessarily in a linear manner. Firstly, we analysed the written answers to develop categories of conceptions pertaining to electric fields, and how students' applied this knowledge to molecules. Secondly, we explored how interaction with the model influenced each student's delivered conceptions. Here, we analysed any emergence of patterns in the data related to the adjustment of electric field concepts that students 'brought' to the model (e.g., Schönborn & Anderson, 2009). Thirdly, we searched for perceptual experiences that could have been responsible for any reconstruction of students' previously delivered conceptions.

Results and Discussion

The findings from the study are structured by responding to each of the two research questions.

What are students' conceptions about electric fields, and how are these applied to a molecular context?

Analysis of the written responses indicated that overall, students had a scientifically sound understanding of electrostatic forces and electric fields. For example, consider the following written answer obtained from S4 in response to probe 1:

> Electric field is denoted E and is measured either in N/C or V/m. If you consider the units you can say that electric field is the amount of force per coulomb. Electric fields arise when there are charges and charges arise in a multitude of places...

As shown above, and in the left SGD in Figure 2 obtained from S5 in response to probe 2, these two students demonstrated a comprehensive Physics-related conception of electric field that also contained the scientific idea that an electric field will arise whenever charges are present. Subsequent analysis showed that four (4/5) of the students were indeed able to successfully discern that since a water (H_2O) molecule contains a charge distribution (e.g., "its charges are separated", S3), it is a polar molecule that shall exhibit an electric field. This reasoning is reinforced in the following response to probe 3, generated by S1:

> The water molecule is polar and it will therefore have two poles which results in an electric field.

However, only a single student (1/5) was able to meaningfully externalise how any corresponding field lines would be associated with the charge distribution across a water molecule (centre SGD, Figure 2). Thus, although student answers revealed an accurate expression of an electric field within a Physics context, transferring this Physics knowledge to a chemical and molecular context was a remarkable challenge. Related to this discovery was a very pronounced association of the existence of electric fields around molecules with the idea of molecular *polarity*. In this regard, students reasoned that *no* electric field would be associated with CO_2 since it is a *nonpolar* molecule. This notion is supported by a response from S1 to probe 3 who stated that since CO_2 is "nonpolar", it is a molecule that exhibits "no field".

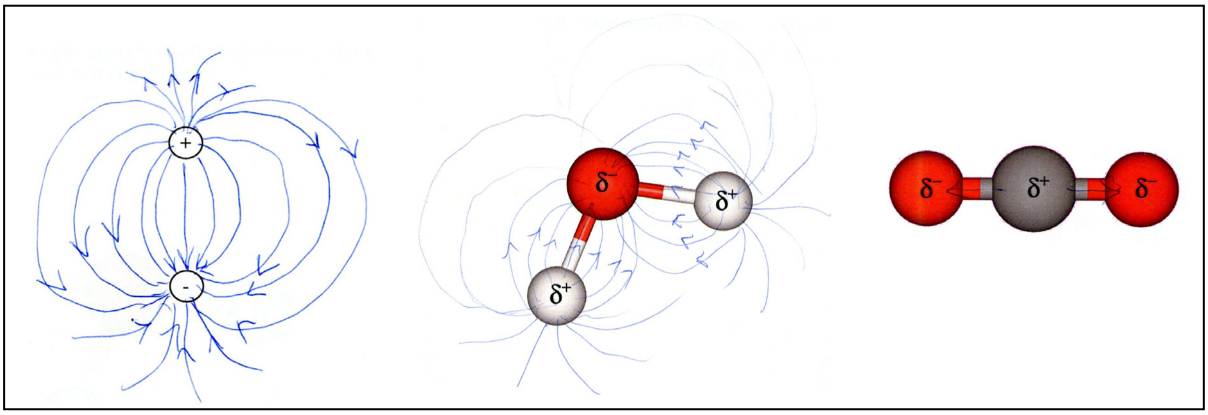

Figure 2. Three SGDs obtained from S5 in response to probes 2 and 3, respectively. The left diagram accurately represents the 'classical' electric field exhibited by two opposite equal charges. The centre diagram is an advanced depiction of the field around an H_2O molecule. However, the electric field that would surround the charge distribution in a CO_2 molecule is not depicted in the right-hand diagram. Instead, two arrows are inserted to erroneously indicate that no electric field arises due to the charges pointing in opposite directions and "cancelling" each other out.

Inappropriate mapping of the idea of chemical nonpolarity onto the absence of an electric field around a molecule may find its source in the manner in which polarity is often presented to students. In our experience, it is not uncommon to find statements in learning resources which claim that a molecule is nonpolar when the symmetry of the molecule is such that any partial *charges* cancel each other (e.g., Russell, Wolfe, Hertz, Starr, & McMillan, 2008, p. 30). This is in contrast with making clear that due to the symmetry of the molecule, there is no *overall dipole*. In fact, this pilot study has exposed such inappropriate reasoning through the following response and accompanying SGD (Figure 2, right) obtained from S5:

> No electric field arises. Negative charges on both sides of the positive cancel each other.

The datum above provides firm evidence for this student's application of such an alternative conception when deducing whether a nonpolar CO_2 molecule exhibits an electric field.

How does interacting with the model influence understanding of electric fields around molecules?

Apart from gaining insight into students' existing knowledge about electric fields, we were interested in exploring the impact of student's actual interaction with the model on these existing conceptions. Two *episodes* that capture how interaction with the model may have influenced students' understanding are presented here.

In a first episode, S1 has previously generated a set of field lines (Figure 3) and enters into the following exchange with the Interviewer (I) regarding the visual representation of the lines:

S1: …you could say that the lines show how it [a charged probe] is affected.

I: Yes, okay, and that you happened to come to [position the stylus at] that particular line, what do you think that depends on, or are there more [lines], how many lines are there?

S1: There should be, there really should be an arbitrary number... because no matter where I end up in this space [volume surrounding molecule] I should be affected [by the field], it should not be that if I come in [position the stylus] between two lines then I will not be affected. (32:48-33:30 min.)

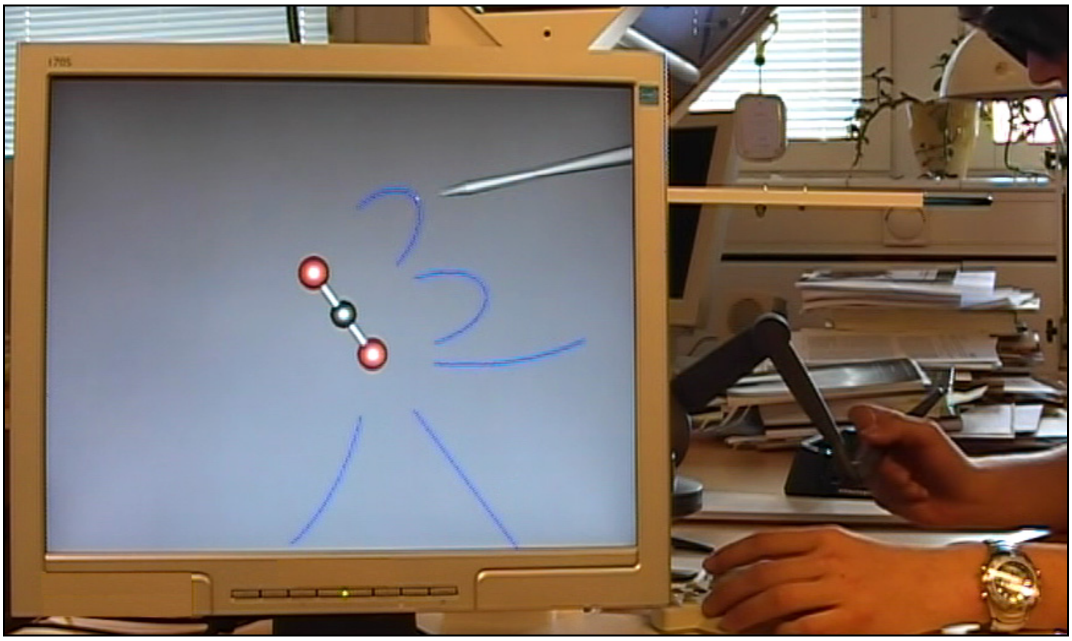

Figure 3. Video screenshot from interview conducted with S1 showing five field lines (blue) surrounding a CO_2 molecule. The shot depicts how S1 positions the probe in close proximity to the uppermost field line. The haptic device (right-hand), stereoglasses (top right) and 3-D mouse (left-hand) that the student manipulates during interaction with the model are also shown.

The student's response above suggests an understanding that field lines are merely a representation of the direction of force that a charged particle would experience. Furthermore, S1 correctly surmises that the electric field could be represented by any number of field lines from an infinite number of possibilities (S1 renders five in this case). Following the interview, S1 suggested that he did not have this knowledge in advance. Hence, this data may serve to illustrate how interacting with the model may provide unique insight into the properties of an electric field that would otherwise be difficult to attain (e.g. Dede et al., 2000).

In a second episode, the following exchange was yielded when S4 interacted with the model whilst the haptic *force and follow* mode was activated:

S4: ...it [the existence of an electric field] had nothing to do with the fact that it [the H_2O molecule] was polar.

I: …did you realise something there?

> S4: Yes I think so, since the oxygen is negative on both sides [the ends of the CO_2 molecule], delta negative or the net charge is negative and the one [atom] in the middle, the carbon, it is positively charged, and the pen [the stylus] is still attracted to the oxygen atoms because they are negative… (26:25-27:25 min.)

Upon previous interaction with an H_2O molecule during the same interview, S4 stated strongly that only polar molecules exhibit electric fields. However, upon interaction with a haptic visualisation of the electric field around a CO_2 molecule, S4 realises that the fact that a water molecule is polar has nothing to do with it exhibiting an electric field. It appears that the datum above may serve as a clear case of where multisensory interaction with the model can be used as a tool for actively challenging existing alternative conceptions, which are difficult to remediate through traditional approaches (e.g. Dede et al., 2000). What is more, this datum provides support for Reiner's (1999) contention that the tactile interface, "acts as a gate to retrieve tacit knowledge and recruit it for learning" (p. 51).

Implications and Future Directions

Prior to interacting with the model, students' written responses revealed that they were not able to separate the concept of *polarity* from *electric field*, which may result in the erroneous view that all nonpolar molecules lack an electric field. One source of this alternative conception might lie in communicating nonpolarity with heavy emphasis on "cancellation of charges". In addition, while dipole moments are conveniently visualised as vectors, higher order multipole expansions are less easily visualised. Therefore, it is unlikely that secondary school students shall be readily exposed to the latter. Together, this might cause students to think that London forces are the *only* possible attractive interaction between nonpolar species, even though quadrupole-quadrupole electrostatic interactions greatly influence the intermolecular properties of CO_2 and benzene (e.g., Vega, Garzón, Lago, & Monson, 1998). One way to alleviate this situation is to incorporate electric field concepts into teaching about polarity and intermolecular interactions. Also, instead of portraying intermolecular forces as neatly packaged 'categories', more emphasis should be placed on the properties common to *all* electrostatic interactions. For example, in addition to 'standard' dipole-dipole and London dispersion interactions, teachers must explicitly state that non-polar molecular charge distributions can also yield attractive intermolecular interactions, based on similar electrostatic principles (e.g., quadrupole-quadrupole interactions).

This study has also presented data showing that tactile interaction may induce students to actively integrate the idea of electric field with molecular charge distribution. The data demonstrates that interaction with the model may encourage knowledge transfer operations by exploiting the dynamic bimodality of the model to develop a formal understanding of electric fields (cf. Reiner, 1999). In turn, a multisensory experience of molecular properties will promote the assimilation of physical and chemical concepts that are otherwise taught and 'boxed' in isolation. Lastly, this work may provide preliminary empirical support for the implementation of such virtual systems in school classrooms. Future studies shall generate data from larger student groups, evaluate additional haptic modes, and incorporate measures for observing students' real time interaction with the system.

Acknowledgements

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School -Based Teacher Training and Education- an Alternate Certification Approach: A Mafikeng Campus Experience: An Impact Study.

Kwayisi, F and Assan, T E B

1. The Problem

The Education, Training and Development Practices Sector- Education and Training Authority (EDTP.SETA) of South Africa entered into an agreement with the North West University- Mafikeng Campus in 2007, to provide Post Graduate Learnership Training (PGLT) to graduates in identified priority subjects such *as Science, Mathematics, Technology, economic – management stud*ies *and computer related studies*. The training was to provide postgraduate certificate in education through school-based learning as an alternate certification to the graduates. The programme served two purposes: firstly it was to "fast- track" the production of teachers for the subjects mentioned above. Secondly to provide classroom-based human resource needs for the schools in those subject areas. The training consisted of 30% contact time and 70% experiential training on the job. Contact sessions were made up content, methodology, teaching and learning theories, skills of teaching, classroom management, and assessment and computer studies. The students were given on site support by the resident teachers and through visits by university lecturers.

This course lasted one year and served as an alternate to the normal one year full-time on campus Postgraduate Certificate of Education (PGCE) course where students have constant contact sessions with a teaching practice period of twelve weeks in the year. The intention of this study was therefore to assess the impact or otherwise, of the school – based programme and to find out if it produced the type of teacher envisaged.

2. Literature

In answer to the question, how do teachers learn from practice, Flick and Lederman (2001) say that the implications of this question go to the heart of current efforts to implement challenging standards in Science and Mathematics education. These standards they contend, are not only concerned with what one teaches but also with how one teaches. They continue that developing expertise in forms of complex instruction requires a view of teaching practice as a discipline. Flick and Lederman (2001) cite Shulman (1986) who refers to two kinds of practical knowledge. He identified propositional knowledge as the way in which teachers accumulate knowledge from practice in the form of maxims or practical roles. One such instructional maxim growing