Transitional Conceptions of the Orientation of the Cross Product in CalcPlot3D

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Students struggle with computing the direction of the cross product in relation to the two vectors that form it, but very little research has involved a non-contextual geometric cross product activity, especially in an online context. This study uses grounded theory to analyze student work completed for a dynamic, online visualization activity. Our preliminary research aims to develop categories that could outline a conceptual model of student understanding of the cross product.

Keywords: vectors, cross products, visualization, transitional conceptions

The topic of determining cross products is prevalent in multivariable calculus, engineering, and physics curricula. Yet, research indicates that students struggle with problems involving the cross product (Knight, 1995; Barniol & Zavala, 2014). In particular students have difficulty determining the direction of the cross product and may not comprehend the non-commutative nature of the cross product (Kustusch, 2016; Scaife & Heckler, 2010). Research on understanding of the cross product has focused on symbolic manipulations. When graphical manipulations have been examined, it has been in a static environment on paper (e.g., Van Deventer, 2006; Zavala & Barniol, 2014). Here, we report on how grounded theory methodology was used to analyze student work in a dynamic virtual environment in order to understand how students communicate the direction and non-commutativity of the vector cross product.

The data for this study came from exploratory activities in the CalcPlot3D applet (Seeburger, 2017). The data set included electronic responses from 434 college-level, multivariable calculus students collected over four years to two embedded questions in the online cross product activity: *Considering the right-hand rule, what is true about the angle between the two vectors when the cross product vector points in the a) positive z-direction and b) negative z-direction?*

The responses were examined for emerging themes through a general inductive analysis (Thomas, 2006) using intercoder reliability where a single response to a single question was treated as the unit of analysis. Four main categories were identified and used for coding. Three were relevant properties to cross product: orthogonality, right-hand rule, cross product magnitude, and one was not: location of vectors. Ainsworth notes that one problem learners face in using multiple representations is retrieval of the relevant information and that this is strongly affected by a learners' familiarity with the topic (2008). Furthermore, developing ideas or "transitional conceptions" (Moschkovich, 1999) gleaned from student responses provided support for the categories created.

We report on the methodology, the findings, and limitations of the study as an initial step in developing a conceptual model of student understanding of cross product. This poster will provide visual displays and supporting evidence for the developed categorization system that allowed representation of both completely correct statements and statements that showed some thought in the category but that the idea expressed was neither correct nor precise.

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