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Student-Created Learning Objects for Mathematics Renewable Assignments: The Potential Value They Bring to the Broader Community

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ABSTRACT

Student-Created Learning Objects for Mathematics Renewable Assignments:
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Having students create Learning Objects (LOs) through renewable assignments has proved more helpful to the student creators compared to disposable assignments in some aspects. Additionally, some researchers have presented evidence where the student-created LOs could benefit the users of the LOs more than traditional learning resources. In this study, I examined a collection of LOs created by college students in the subject of mathematics to understand the nature of the value that a student-created LO could bring to other learners.

By extending a framework for non-disposable assignments (Seraphin et al., 2019), I evaluated 3 components that affect the value of the LOs: design, accuracy, and visibility. The results show that some intended users of the student-created LOs could benefit from using the LOs. However, the intended users of the LOs may not come across those LOs even if they searched specifically for the LOs. Subsequently, it is concluded that LOs created to be used in future iterations of the same class may be more practical in bringing value to the broader community.

Keywords: renewable assignment, student-created learning objects, open pedagogy

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CHAPTER 1: RATIONALE

Doing homework assignments is a regular routine for mathematics students. Despite the potential benefits, however, almost all homework assignments end up in the trash can or recycling bin. Seeing this amount of time being dedicated to products that are going to waste, some researchers have considered ways to better utilize the tradition of homework assignments. Wiley (2013) introduced the idea of renewable assignments, as opposed to disposable assignments, and later claimed that renewable assignments "both support an individual student's learning and result in new or improved open educational resources that provide a lasting benefit to the broader community of learners" (Wiley & Hilton, 2018, p. 137). In other words, instead of spending time on disposable practice problem sets, renewable assignments invite students to create learning objects (LOs) that could be used by others in their own learning. By classifying types of LOs and synthesizing multiple definitions of an LO, Churchill (2007) came up with a simple definition for an LO, which is "a representation designed to afford uses in different educational contexts" (p. 484). This definition is made purposefully broad to include all types of representation in all educational contexts. And this broad definition of an LO works well with the definition of a renewable assignment because products of renewable assignments can be represented in many ways and for many purposes. Under this definition, all products created for renewable assignments would be LOs. Such LOs could include, for example, study guides, practice exams, worked examples, visual aids, tutorial videos, etc.

Wiley and Hilton (2018) defined a renewable assignment as an assignment that asks students to create, share publicly, and openly license an artifact that has educational value to others--what I am referring to as an LO. An open license gives all users the permission to freely use, copy, edit, and distribute the content. The creation and the public accessibility of an LO are readily observable. The qualification of an open license could also be determined easily and objectively. To understand how valuable an LO is to its potential users, however, requires a subjective assessment of that potential value. One might wonder how these student-created LOs could "provide a lasting benefit to the broader community of learners" (Wiley & Hilton, 2018, p. 137) when their creators are learning the same pieces of mathematics that are presented in their LOs. To further complicate this assessment, in the subject of mathematics, there already exist LOs on many topics covered in K12 and lower college level mathematics courses on the internet. It may seem unrealistic to expect that these student-created LOs could add value to a vast collection of professionally created LOs that is available on the internet. This is a question that should concern all mathematics teachers and students that wish to better utilize the time spent on homework assignments by implementing and engaging with renewable assignments. To clarify, the three actors related to renewable assignments and LOs are: the teacher that assigns a renewable assignment to students, the student that becomes a student-creator by creating an LO to fulfill the requirement of the renewable assignment, and the potential users of the LO that may choose to use such an LO after it has been created and published. This study will explore the nature of the potential value that student-created LOs for renewable assignments bring to the broader community—to the potential users of the LO.

CHAPTER 2: LITERATURE REVIEW

Researchers have found that renewable assignments benefit student creators in various ways. For example, students developed a deeper understanding of the topics covered by the assignments (Croft et al., 2013; Reyna & Meier, 2018; Schreiber & Klose, 2017b), and performed better than their peers when they were given renewable assignments (Crow, 2006). Students also found the work they were asked to do more meaningful (Allan et al., 2017; Andone et al., 2020; Pitt, 2017). And as a result, they were more motivated (Schreiber & Klose, 2017a) and engaged (Lansdown, 2010) in the process. Other benefits include opportunities to improve creative thinking (Rosedale et al., 2021), research skills (Lower, 2015), and digital literacy (Hoban et al., 2013). Although there are many benefits to the student creators of the LOs, it is not clear what kind of values these LOs bring to the broader community.

Although Wiley and Hilton (2018) provided a few examples of renewable assignments that aimed to bring value to the broader community, there is not very much research done on the value that student-created LOs could bring to the broader community. While some teachers may be hesitant to replace teacher instruction or traditional learning sources with student-created LOs (Lansdown, 2010), one study found that student-created LOs were more effective in preparing students for labs of a chemistry course when compared to TA instructions (Jordan et al., 2016). More specifically, student volunteers who had completed the same chemistry course in the last two years and who had digital production skills created a video presentation for a specific laboratory experiment. The video presentation was created under the supervision of a faculty member and had gone through a peer-review process. Students were then put into two groups prior to the laboratory experiment, where one group received the video presentation, and the other group received TA instruction. The study found that although the TA group had a higher self-reported understanding, the video group performed better and required less assistance during the laboratory experiment. This study provides evidence that student-created LOs could increase student performance when used to replace traditional education resources.

Another study reported that some student creators believed their representation of certain mathematical procedures could provide a better scaffolding to their fellow students than content presented by the lecturers (Croft et al., 2013). For example, the student creators said, "once we do understand it we are probably better at explaining it to another student than possibly [the lecturers] might be" (p.1050). One of the lecturers in this study also noted,

> [Students probably have] more knowledge of where exactly the students are struggling. Pointing exactly at the right places where the lecturer might think the students have understood when they haven't actually because the feedback loop is not as closed as it should be. (p.1051)

This study showed that student-created LOs can possibly bring a special perspective to its users that traditional education resources cannot.

The two studies above illustrated that student-created LOs could add value to the community and a possible reason behind the added value, which is a student's perspective on a challenging topic. Overall, there are many research studies that show renewable assignments are beneficial to the student creators. And the two studies that exist show that student-created LOs could have a greater impact than traditional resources. However, it is unclear which aspects of these LOs contribute to the added value. In order to further research related to student-created LOs for renewable assignments and help teachers bring the potential value of those LOs to realization, we must first understand the potential value of these student-created LOs.

CHAPTER 3: THEORETICAL FRAMEWORK

In this study, I explored the nature of the potential value of student-created LOs from renewable assignments. Some of the first things to understand are the definition of a renewable assignment, the definition of an LO, and the approach I am taking to assess the value of an LO.

Wiley and Hilton (2018) proposed a four-part test that can be used to determine whether an assignment is renewable (see Figure 1). In short, for an assignment to be renewable, (1) the students would be asked to create an LO, either from scratch or by revising/remixing, (2) the LO would have educational value to others, (3) the students would be asked to share the LO publicly, and (4) the students would be asked to openly license their LO. Even though Wiley and Hilton did not explicitly define "value" in their article, from the examples they provided, an LO has a value if it provides an opportunity for its users to engage in a learning experience. Although a binary understanding of value is appropriate for the four-part test, for the purpose of this study, a framework through which to understand the magnitude of this value is provided at the end of this section.

Figure 1

Criteria Distinguishing Different Kinds of Assignments

	Student creates an artifact	The artifact has value beyond supporting its creator's learning	The artifact is made public	The artifact is openly licensed
Disposable assignments	X			
Authentic assignments	X	X		
Constructionist assignments	X	X	X	
Renewable assignments	X	X	X	X

Note. From "Defining OER-Enabled Pedagogy," by D. Wiley, and J. L. Hilton, 2018, *International Review of Research in Open and Distributed Learning, 19*(4), p. 137 (https://doi.org/10.19173/irrodl.v19i4.3601).

There are many frameworks that could be used to determine the magnitude of the value of an LO, (e.g., Haughey, 2005; Kurilovas et al., 2011; Morgado et al., 2007). One framework that is particularly useful for the purpose of this study was developed by Seraphin and colleagues (2019). Their framework is designed to evaluate student-created LOs for non-disposable assignments, or LOs that "[have] value beyond supporting [their creators'] learning" (see Figure 1), which include renewable assignments. Their framework outlines three dimensions of LOs created for a non-disposable assignment: time, space, and gravity. The time dimension refers to the amount of time for which an LO has an effect on people's learning. Some LOs created for non-disposable assignments may be used in a classroom for a day, a semester, or a school year. On the other hand, LOs created for renewable assignments are meant to exist and evolve forever.

The space dimension refers to the physical or digital space in which an LO exists. The space continuum (Classroom-Institution-Community-World) in their framework would automatically put LOs for renewable assignments in the top level because the LOs are accessible to everyone on the internet. The gravity dimension refers to the amount of potential value an LO has. The authors further defined internal and external gravity to be the potential value the LO has for the creators (internal) and for the users (external).

Since LOs created for renewable assignments are usually publicly accessible on the internet, the time and space dimensions would be maximized by definition. The gravity dimension--more specifically external gravity, which is about the amount of potential value an LO could bring to the broader community--perfectly aligns with the focus of this study. Seraphin and colleagues (2019), however, did not provide a clear definition for external gravity. Instead, they provided some examples of external gravity: "the learning impact for... fellow student/public consumers... of the final learning product" (p. 90), "the learning benefit to the community or society" (p. 90), and "the classmate/peer-teaching benefit or impact on the larger community" (p. 91). Although these examples are helpful in illustrating the essence of external gravity, there is not a definition and/or framework through which external gravity can be qualified. Moreover, similar to the way people in different locations experience gravity differently, the actual value of an LO might differ when looked at through different perspectives.

As a result, for this study, my focus is on understanding the potential value of student-created LOs to its intended users from the perspective of a mathematics educator. To do this, I first theorized the factors of an LO that I would look at as an educator when considering whether I would use it, and those factors became the frame through which I determine the potential value of an LO. As I looked at those factors across multiple LOs, some of those factors were adjusted to better reflect the usability an LO could afford its users. In other words, I look at an LO as if I am a teacher and determine how likely I would recommend the LO to my students. Given the fact that these student creators are at best amateurs in both mathematics and education, it may seem unrealistic for a teacher to recommend any student-created LOs over the many professionally created resources available online. However, LOs created for renewable assignments are supposed to add value to what already is. If all factors of a student-created LO are significantly worse than that of the existing resources, there is no reason for anyone to choose to use the LO over the existing resources. Therefore, for a student-created LO to bring an added value to the community, some factor related to usability of a student-created LO should have a level of quality that is similar to what is currently available. The purpose of this study is to look only at the LOs and determine how valuable a learning experience the LOs could afford users. Therefore, I do not focus on the experience of the student-creators, nor the experience of any actual users of the LOs. Furthermore, I define the potential value an LO has to its users to be the meaningfulness of the learning experience it affords its users, and also define external gravity to be the magnitude of that potential value. In other words, the external gravity of an LO is how useful it is to its users, or, its usability. Therefore, to understand the nature of the potential value that student-created LOs bring to the broader community, I provide a theoretical framework for external gravity (hereafter referred to as *usability*) in the following paragraphs.

There are many factors that could affect the usability of an LO, which is the magnitude of potential value the LO affords its users. For example, an LO that teaches a new concept should contain more details and examples than one that reviews a taught concept. The pedagogical reasoning behind an LO should take into account its intended purpose and the background knowledge its intended users have. The presentation of an LO should also match its intended purpose. For example, an LO created to help teachers present a lesson should be presented as a lesson plan, or as a document formatted to highlight key understandings, anticipated student thinking, or possible teacher moves. The design of an LO should be evaluated based on the stage of learning of its intended users, and its intended purpose. I refer to the ideas of an LO fitting its intended users and its intended purpose as the *design* component of usability.

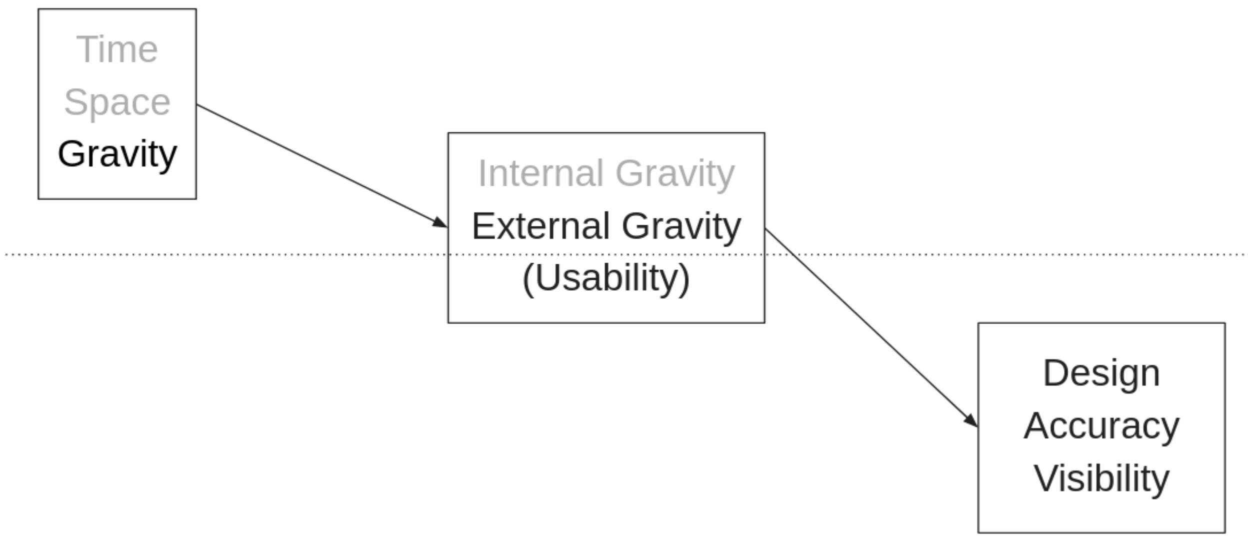
Although *design* is an important component of usability, it is certainly not the only one. A well-designed LO would still need to contain correct and complete content in order to bring actual value to its users. Correctness impacts the usability of an LO because a mathematically inaccurate LO would not help its users to learn mathematics correctly and so would have less educational value. The same applies to the completeness of the representation of the mathematics. In addition, the proximity of the inaccuracies/incompleteness to the central idea of the LO also affects its value. If the inaccuracy/incompleteness is within the central idea of LO, then it would have a greater negative impact on the usability of the LO. I refer to the ideas of correctness, completeness, and proximity mentioned above as the *accuracy* component of usability. Compared to the component *design* that focuses on how an LO is presented, *accuracy* focuses on what an LO presents.

Lastly, a well-designed and accurate LO still would not bring much value to the community if it is unlikely for its intended users to come across it. In other words, if an LO does not show up on an internet search early enough, then its value would likely not come to realization because no one might actually use it. One important distinction to note here is the difference between this *visibility* component and the space dimension proposed by Seraphin and colleagues (2019) mentioned in the theoretical framework. The *visibility* component is about the likelihood of the intended users coming across an LO, whereas the space dimension is about the accessibility of the space where an LO exists. All of the LOs created for renewable assignments should be accessible to anyone through the internet. However, given the vast amount of information on the internet, not everyone would come across a particular LO through an internet search. There are two ways someone could come across an LO through an internet search. The first is a general search of the internet, such as a Google search. The second is a search within the host platform of the LO, a specific subset of the internet, such as Youtube (https://www.youtube.com) for a video LO. I refer to the likelihood of someone coming across the LO as the *visibility* component of usability.

In summary, to better understand the nature of usability of mathematics LOs created for renewable assignments, analysis for this study will focus on the three components just described: *design*, *accuracy*, and *visibility*. Figure 2 shows the relationship between the framework I use for this study (below the dashed line) and the framework by Seraphin and colleagues (2019). Therefore, this study aims to answer this research question: What is the nature of the usability of student-created mathematics LOs from renewable assignments?

Figure 2

A Diagram of the Theoretical Framework



Note. Adapted from “A conceptual framework for non-disposable assignments: Inspiring implementation, innovation, and research,” by S. B. Seraphin, J. A. Grizzell, A. Kerr-German, M. A. Perkins, P. R. Grzanka, and E. E. Hardin, 2019. *Psychology Learning & Teaching*, *18*(1), pp. 84–97 (https://doi.org/10.1177/1475725718811711).

CHAPTER 4: METHODS

Data Collection

To understand the nature of the usability of student-created mathematics LOs, it is helpful to study a substantial collection of real life examples. It would be even more beneficial, for control purposes, if the collection of LOs is done under the direction of the same teacher because the LOs should meet certain common criteria such as the topics of mathematics, and the time and/or effort expected to be put in the creation of the LOs.

Andrew Misseldine, a mathematics professor at Southern Utah University, has incorporated renewable assignments in his courses since 2017. Furthermore, he has documented his descriptions of the assignments and publicly shared the openly-licensed LOs created by his students (Misseldine, n.d.). There are a total of 66 LOs in Misseldine's online collection: 4 in Contemporary Mathematics, 10 in Calculus III, 42 in Modern Geometries, and 10 in Abstract Algebra. Given the purpose of this study, I decided to analyze the 52 LOs from Calculus III and Modern Geometries. Abstract Algebra is excluded because of the efforts required to properly evaluate the mathematics in those LOs, which is only one of three areas of interest. Contemporary Mathematics is excluded because there are only four LOs created for that course, which may limit the way we understand those LOs within their context. There are 11 different types of LOs in the 52 LOs that made up the data set for this study (see Table 1).

Table 1

The Count of Various Types of the LOs Analyzed for this Study

Type	Count
Lesson Plan	16
Visual Aid	11
Video Tutorial	11
Exam Prep Tool	5
Game	3
Classroom Activity	1
Lecture Note	1
Tutorial	1
Children's Book	1
Poem	1
Song	1
Total	52

One of the advantages of using this subcollection of LOs from Calculus III and Modern Geometries is that this is a substantial collection of comparable LOs created under the direction of the same professor. There are few other student-created LOs for mathematics renewable assignments that can be found on the internet. In addition, those LOs are scattered and they are usually not accompanied by the assignment descriptions, without which it is difficult to tell whether those LOs were actually created to fulfill a renewable assignment. In addition, as mentioned above, since these LOs were created under the direction of the same instructor, there are some commonalities among these LOs. This commonality allowed for meaningful comparison among the LOs in this collection. However, using only one collection from the same professor introduced a limitation. This dataset limited the generality of the results. Since the focus of this study was to explore the nature of the value of these LOs, or their usability to the potential users, and not to make generalized claims about these LOs, the advantages of using this dataset outweighed the disadvantages.

Data Analysis

To explore the 3 components of the usability of each of these LOs, the following questions were considered:

Design

- *What is the format (e.g., text, video, audio, digital manipulative) of the LO?*
- *At what stage of learning are the users of this LO expected to be?* (This is determined based on the description of the LO and also the level of detail of the mathematical content in the LO.)
- *How might a teacher/expert create this LO differently?* (This is determined through a comparison between the student-created LO and other resources that are available online. It is because some aspects of a student-created LO would need to have a similar level of quality as the existing resources to contribute an added value.)

Accuracy

- *Does the LO accomplish its perceived purpose?*
- *What, if any, are the mathematical inaccuracies in the LO?*

- *What relevant mathematics, if any, is omitted in the LO?* (This question is part of accuracy rather than design because it focuses on *what* the LO presents instead of *how* something is presented.)

Visibility

- *Is it likely for someone to come across this LO through a Google search?*
- *Is it likely for someone to come across this LO through a search on the host platform of the LO?*

Below is an example of an analysis of a typical LO (Derivatives Tutorial). This LO is a video that features a top view of real-time writing on pieces of paper accompanied by a voice over. This video was selected because videos make up about one third of the collection of LOs, and its content is a popular introductory topic in college mathematics. Similar analysis was done to all the LOs in the dataset.

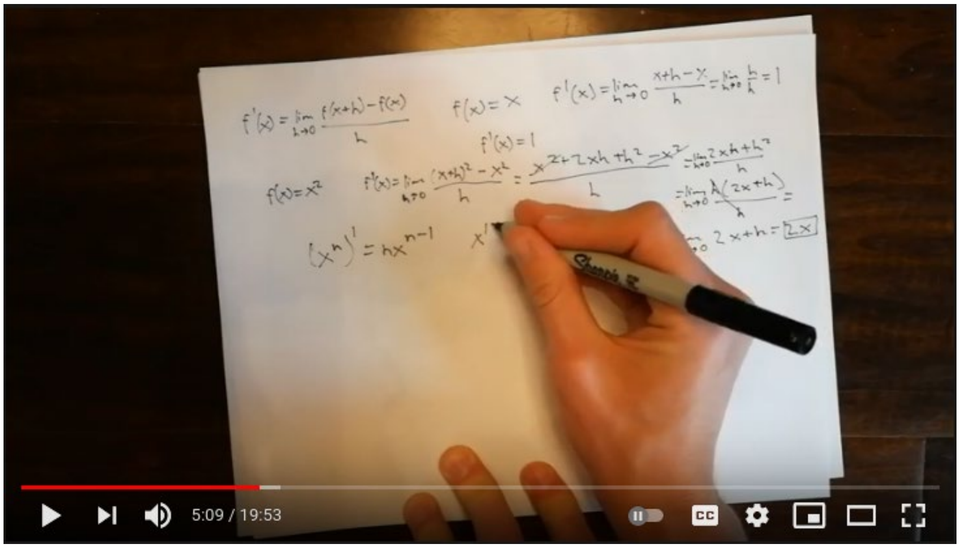
Design (example)

What is the format of the LO?

- This LO is a lightly-edited non-scripted video that shows a human hand writing on a piece of paper with voice over explaining the mathematics on the paper (see Figure 2). Errors are made and corrected multiple times in the video.

Figure 3

A Screenshot of the Derivatives Tutorial LO



At what stage of learning are the users of this LO expected to be?

- This LO goes over the procedure of calculating the derivative by using the definition and some differentiation rules. Users that do not have prior experience would not understand the meaning of a derivative from this LO. Instead, they would see some applications of differentiation rules, which would not mean much to them. Therefore, the potential users of this LO are people that have learned about the meaning of derivatives before.

How might a teacher/expert create this LO differently?

- The student creator first goes through two examples of finding the derivatives of x and x^2 by using the definition of derivative. Then he tries to convince the audience of the validity of the power rule by pointing out the two-step pattern shown in his two examples. By contrast, the textbook (Stewart, 2015) provided four examples of finding the derivative using the definition (x, x^2, x^3, x^4) before introducing the power rule. While both the student creator and the expert aimed to help their audience recognize the pattern of the power rule, the rule of the pattern is more generalizable when given four steps than two steps. In fact, when given only two steps of a pattern, there are different ways to reasonably describe a general pattern.

- An expert might consider writing on a digital surface instead of a physical one so that the content could be better shown on a screen. They might also use a script and/or editing techniques to minimize errors in the video. Using a digital surface could help the student creator to raise an aspect of this LO closer to a professional level that matches other available resources.

Accuracy (example)

Does the LO accomplish its perceived purpose?

- At the very beginning of the video "Derivatives Tutorial" the student creator said "I will be going over the definition of the derivative and some basic techniques for how to derive functions." Therefore, the stated purpose of the video is doing some unspecified mathematical activity related to the definition of a derivative and the basic rules (e.g., product rule, quotient rule) for finding the derivative.
- Somewhat consistent with the stated purpose, the video goes through the mathematical definition of a derivative in the first 4 minutes. The remaining 15 minutes of the video is spent on stating the derivative rules and going over examples of those rules.

What, if any, are the mathematical inaccuracies in the LO?

- The student creator used the word "derive" when he meant "differentiate". For example, when the student creator first introduced the purpose of the video, he referred to the rules for differentiation as "basic techniques for how to derive functions." The same terminology mix-up happened again when the student creator was going through his first example. He said, "If we were to derive this function right here, …" Even though differentiation is at the core of the LO, mixing up the terms “derive” and “differentiate” does not seem to be closely related to the mathematical ideas of the videos. However, based on the time allotment of the video, the focus of the video is the procedures and applications of the rules of derivatives. Therefore, even though this error happened many times throughout the video, it is not counted as a significant error.

- There was also one occasion where “factor” was used incorrectly when the action was “expand.” This happened when the student creator was demonstrating the usefulness of the chain rule and explained that the function $f(x) = (x^2 + 1)^3$ could be differentiated quicker by using the chain rule than to “factor that whole thing out.” But the difference between factoring and expanding is not the focus of this LO. In addition, the action itself was carried out correctly and demonstrated clearly in the video.

What relevant mathematics, if any, is omitted in the LO?

- There is no mention of differentiating a sum or a difference in the video. The sum and difference rules are two basic rules of derivative, which is the main focus of this LO. In addition, the textbook (Stewart, 2015) for their calculus class covers the sum and difference rules in between the power rule and the product rule, which could be found in the video. The lecture notes used by the professor also have the sum and difference rule in a similar place. Without the knowledge of these two rules, the users of this LO may not be able to quickly take the derivative of some simple functions such as $f(x) = 2x + 1$ without going back to the definition. By not introducing or even mentioning the sum and difference rule, this LO presents an incomplete picture of its main focus, which is the basic rules of derivative.

Visibility (example)

Is it likely for someone to come across this LO through a Google search?

- When a Google search is done by using the nature of this LO as the search phrase (Derivatives Tutorial, "derivative rules" review) this LO does not show up within the first three pages of results. Therefore, it is unlikely that someone looking for something similar to this LO would find it through a Google search.

Is it likely for someone to come across this LO through a search on the host platform of the LO?

- When a similar search is done on the host platform of this LO (Youtube), this LO does not show up within the first three pages of the results. So it is unlikely for someone to come across this LO even if they were searching within the host platform of the LO.

Similar analyses were done for each of the 52 LOs. The findings, or answers to the questions above, were sorted and grouped based on their similarity. Each of the groups was then given a description. Once the groups captured the ideas in the answers to the questions above, themes were identified based on the description of the groups. Some of the themes were apparent from the beginning. For example, the format of the LOs were categorized as they were being coded. Other themes seemed to follow a hierarchy. For example, some inaccuracies within an LO seemed to have a more significant impact on usability than the others. Once those inaccuracies were separated based on how much it would likely affect the intended users for the intended purpose of the LO, further analyses were done to identify the reasons why some of those inaccuracies were less problematic. And there were themes that emerged only after the answers to the questions above were categorized. For example, the ways in which experts might improve a given LO. In the next section, those themes and the codes for those themes are explained.

CHAPTER 5: RESULTS

By looking across the results of the individual analyses of the LOs, themes within the three components of usability emerged and were identified. Those themes, the relationships between the themes, and their frequencies are presented here.

Individual Components

Design

The first component of usability is *design*. In this component, I examined three themes: the format of the LOs, the stage of learning at which the intended users are expected to be, and the possible improvements of the LOs that could be made by an expert. In the Data Collection section, I introduced the different types of the LOs in the dataset: lesson plan, visual aid, video tutorial, exam prep tool, game, classroom activity, lecture note, tutorial, children's book, poem, and song (see Table 1). In the following paragraphs, descriptions of the different types of the LOs are provided.

Type

The most popular type of LO is lesson plan, which could be a result of the overlap between the broad coverage of the class "Modern Geometries" and geometry in secondary education, and the fact that this geometry class is required for mathematics education majors. All of the lesson plans were created by students in the Modern Geometries class, and most of the lesson plans follow a specific template called the Integrated Core Applied Project (ICAP) provided by the university to the students (see Figure 4). The biggest part of the ICAP template is the step-by-step teacher script that students are supposed to create. Therefore, it is not difficult to visualize the teaching and learning from reading the lesson plans.

Figure 4

The Beginning Part of the 7th Grade Geometry Lesson Plan LO

Southern Utah University – Teacher Education
Integrated Core Applied Project (ICAP)

Name	Brynnli Kitchen	Grade Level/Content Area:	7 grade mathematics	Estimated Time	20
Standard: (Utah Core Standard(s): Standard 7.G.5					
Integrated Content Areas: Geometry in math					
Learning Objective(s): (*Each content area listed needs to have a learning objective): SWBAT... Use facts about supplementary, complementary, vertical, and adjacent angles in a multi-step problem to write and solve simple equations for an unknown angle in a figure.					
Essential Question(s): what are the definitions of supplementary, complementary, vertical, and adjacent angles.					
Materials: outline for students, computer, prepared Kahoot					

***Complete the following sections of the lesson plan using:** red or **bold type –** to script what teacher says, blue or regular type – to script what students will do, green or *italic type* - for what is to be written on the board or a chart

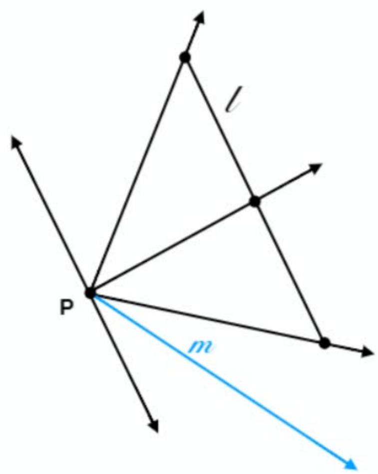
LESSON PLAN SHOULD INCLUDE ENOUGH DETAIL THAT SOMEONE ELSE WOULD BE ABLE TO TEACH IT.

Time **Number of min. for each component*	**Lesson Components**	**Instructional Language/Teacher Script/Activities** **Scripted step by step for each lesson component. *Remember to add in essential questions when applicable.*	**Engagement** Describe in detail what students will be DOING.	**Technology Integration** **How will I MEANINGFULLY integrate technology?*	**Assessment** **Documentation *Outcomes *Pre and Post *Formative/ Summative *Rubric, Project *Observation *Paper/Pencil *Reteach concepts* *Use Assessment Menu*	**Reflection** **How did the students respond *What do I need to change *New ideas to improve this section*

All the visual aids come from a collection called Progressive Geometry Proof (PGP). Each PGP in this collection is based on a theorem taught in the Modern Geometries class (see Figure 5). A PGP operates like a slideshow where the complete text of the theorem is shown next to some whitespace at the very beginning. As the user clicks through the PGP, each sentence of the theorem is highlighted and the geometric construction associated with the highlighted sentence shows up in the whitespace. At the end, a complete figure of the theorem is shown alongside the text of the theorem.

Figure 5

A Screenshot of a PGP LO



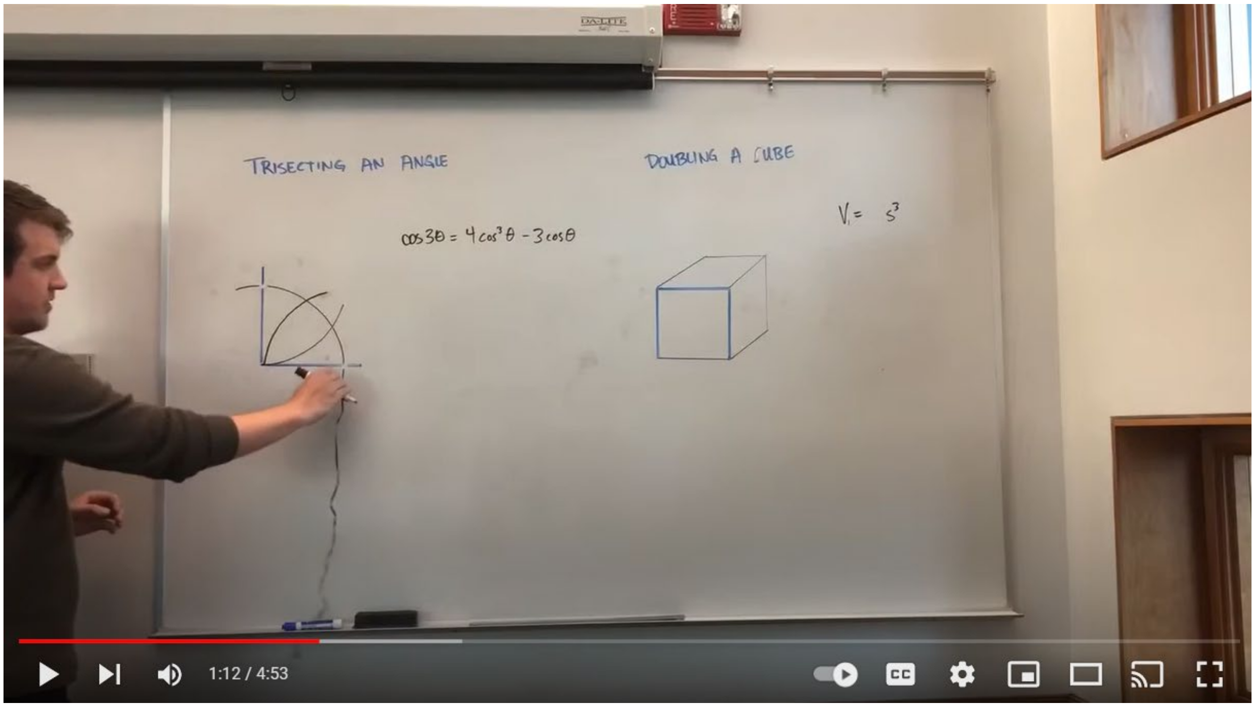
Proof. Let P be a point in the geometry. Since not all points are on the same line by Axiom 3, there must be a line ℓ which does not contain P. Then for each point on ℓ, there is a unique line containing this point and P by Axiom 4. Likewise, these three lines are all distinct (otherwise the uniqueness of Axiom 4 is violated). Finally, there is a unique line containing P which is parallel to ℓ by Axiom 5. Thus, there are at least 4 lines incident to P.

Let m be another line incident to P that was not considered before. It cannot be parallel to ℓ, otherwise the uniqueness of parallel lines would be violated. Hence, m intersects ℓ. Call their intersection Q. Then m is the unique line determined by P and Q. Since Q is on ℓ, this line was already considered above, which leads to a contradiction. The result then follows. □

Video tutorials are videos that focus on some specific mathematical topics, such as the example shown in the Data Analysis section. Other topics for video tutorial LOs include geometric constructions, a geometry theorem, and an integration technique. Like the example in the Data Analysis section, some of these LOs show a human hand writing on a piece of paper with a voice-over, some show writings on a digital surface also with a voice-over, and others show the student-creators standing in front of a whiteboard writing and talking (see Figure 6).

Figure 6

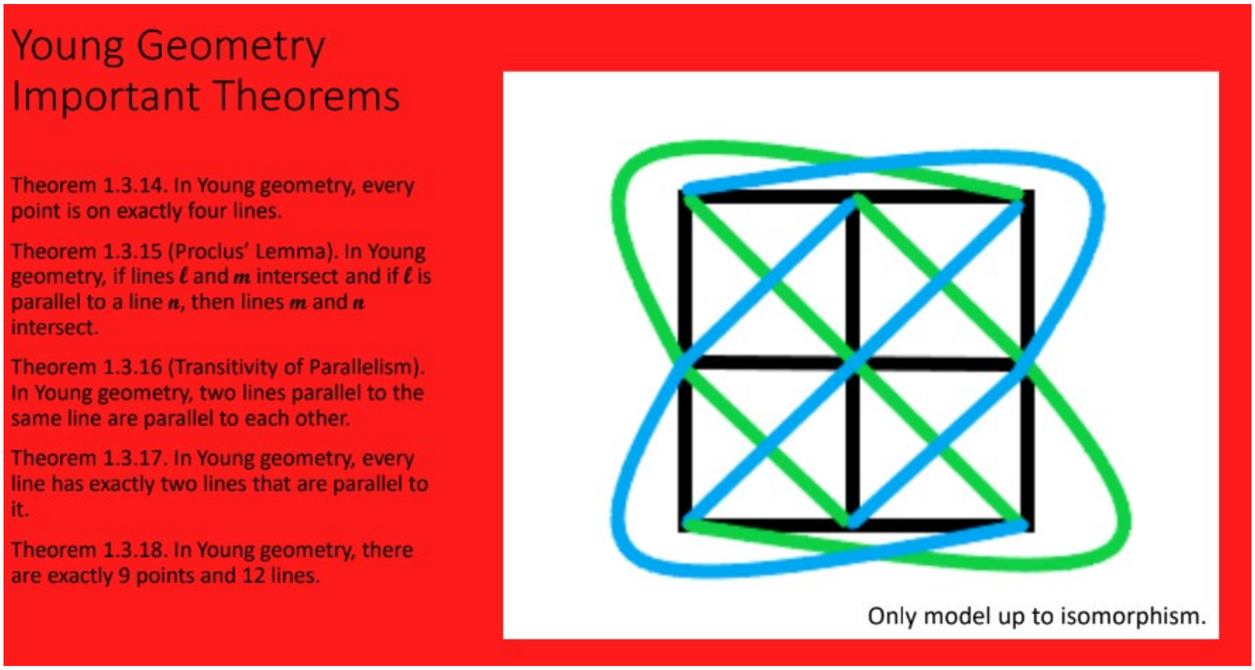
A Screenshot of an LO about Geometric Constructions



The exam prep tools come in different formats. There are digital flashcards detailing definitions and formulas to memorize for a calculus exam. There is a practice exam with an answer key. There is a slideshow containing axioms, theorems, and models for a geometry exam (see Figure 7). There is also a video showing a person going through the materials for a specific exam.

Figure 7

A Screenshot of an Exam Prep LO



Two types of games are in this dataset: Jeopardy and a card game based on Fluxx with a geometry theme. The Jeopardy games have a main screen of the 25 choices of questions in a clickable 5x5 grid (see Figure 8). Each of the questions has its own display of question and answer. The card game is a document that contains the printouts of all the cards needed for the game (see Figure 9) and also the rulebook for the game.

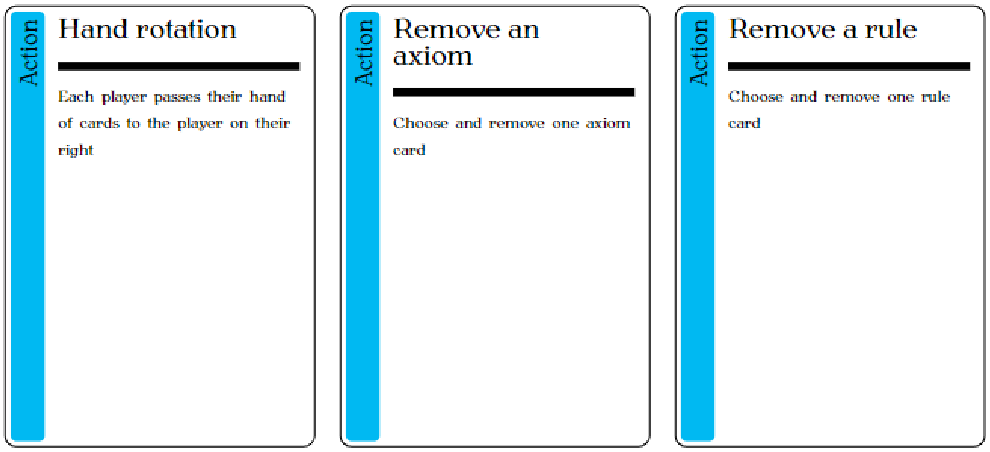
Figure 8

A Screenshot of a Jeopardy LO

LIMITS	DERIVATIVES	INTEGRALS	TRIG FUNCTIONS	AREA/ VOLUME
100 points	100 Points	100 Points	100 Points	100 Points
200 Points	200 Points	200 Points	200 Points	200 Points
300 Points	300 Points	300 Points	300 Points	300 Points
400 Points	400 Points	400 Points	400 Points	400 Points
500 Points	500 Points	500 Points	500 Points	500 Points

Figure 9

Some Cards from a Card Game LO

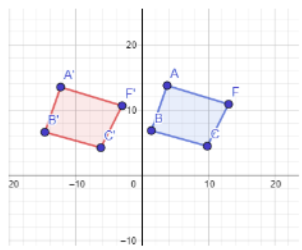
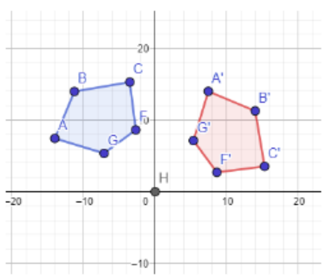


The classroom activity in the dataset is a document that outlines a matching activity that teachers can use with their students. The topic for this activity is function transformation. Printouts of both graphical and algebraic representation of the transformations are provided as part of the LO (see Figure 10).

Figure 10

The Matching Game of a Classroom Activity

Transformations Matching Game

	Translated to left 8 units.
	Rotation 90 degrees clockwise around the origin.

The lecture note in the dataset is a document that is created as an appendix to the lecture notes created by the same professor that gave the renewable assignment to the students (see Figure 11). The topic for this lecture note is Peano’s Axioms that uses the axiomatic system to describe the natural numbers. This LO is styled according to the professor’s lecture notes.

Figure 11

Part of a Lecture Note LO

"Natural selection is anything but random." –Richard Dawkins

APPENDIX A

PEANO'S AXIOMS

STEPHANIE HANSEN AND ANDREW MISSELDINE

Apx A. Axioms of Peano

The Peano Axioms are a set of axioms for the natural numbers presented by 19th century Italian mathemathician Giuseppe Peano. These axioms have been used in a number of metamathematical investigations, including research into whether number theory is consisent and complete.

Peano's Axioms

Undefined Terms: "$\mathbb{N}$", "0", and "σ".

Axiom 1 (Set Interpretation): The symbol $\mathbb{N}$ denotes a set, called the **set of natural numbers**. Furthermore, $0 \in \mathbb{N}$, called **zero**, and $\sigma : \mathbb{N} \to \mathbb{N}$ is a function, called the **successor function**.

Axiom 2 (Nonzero Image): The image of $\sigma : \mathbb{N} \to \mathbb{N}$ does not contain 0.

Axiom 3 (Injectivity): The function of $\sigma : \mathbb{N} \to \mathbb{N}$ is injective.

Axiom 4 (Induction): Suppose $S \subseteq \mathbb{N}$ such that $0 \in S$ and $n \in S$ implies $\sigma(n) \in S$ for all $n \in \mathbb{N}$. Then $S = \mathbb{N}$.

Definition Apx A.1. Suppose $a, b \in \mathbb{N}$. We say that b is a **successor** of a if $\sigma(a) = b$. Likewise, we say that a is a that a is a **predecessor** of b if b is a successor of a. We say that b is a has a predecessor in $\mathbb{N}$ if there exists an $x \in \mathbb{N}$ such that x is a predecessor of b. Let 1 denote the successor of 0.

Note that by the Injectivity axiom (Axiom 4), each natural number has a unique successor.

The LO categorized as a tutorial is a webpage about derivatives (see Figure 12). This webpage uses everyday language to describe ideas surrounding derivatives, including notation, basic rules, and simple applications.

Figure 12

A Screenshot of a Webpage about Derivatives

Rules for Differentiation

Constant Rule: The derivative of any constant is always zero.

Example: (d/dx)12=0

Power Rule: The derivative of a variable to a power is equal to the power times the variable raised to a power one less than the previous power.

Example: (d/dx)x^6=6x^5 Example: (d/dx)x^(y)=yx^(y-1)

Constant Multiple Rule: A constant multiplied by a variable does not change when taking the derivative.

Example: (d/dx)5x^2=5(d/dx)x^2=5(2x)=10x Example: (d/dx)nx^3=n(d/dx)x^3=n(3x^2)=3nx^2

Sum/Difference Rule: When taking derivatives of a function with more than one of the same variable that is added or subtracted, the derivatives can be taken separately.

Example: (d/dx)(3x+3x^2)=(d/dx)3x+(d/dx)3x^2=3+6x

Product Rule: When taking a derivative of a function with more than one of a variable that is multiplied, take the first variable times the derivative of the second plus the second variable times the derivative of the first.

Example: (d/dx)xsin(x)=xcos(x)+sin(x)(1)=xcos(x)+sin(x) Example: (d/dx) (x^2)cos(x)=(x^2)(-sin(x))+cos(x)(2x)=-x^2sin(x)+2xcos(x)

Quotient Rule: When taking a dervitative of a function with more than one of a variable that is divided, take the bottom times the derivative of the top minus the top times the derivative of the bottom, all over the bottom squared.

Example: (d/dx) (2x/x-1)= [(x-1)(2)-(2x)(1)]/(x-1)^2 Example: (d/dx)x/sin(x)=(xcos(x)-sin(x))/sin(x)^2

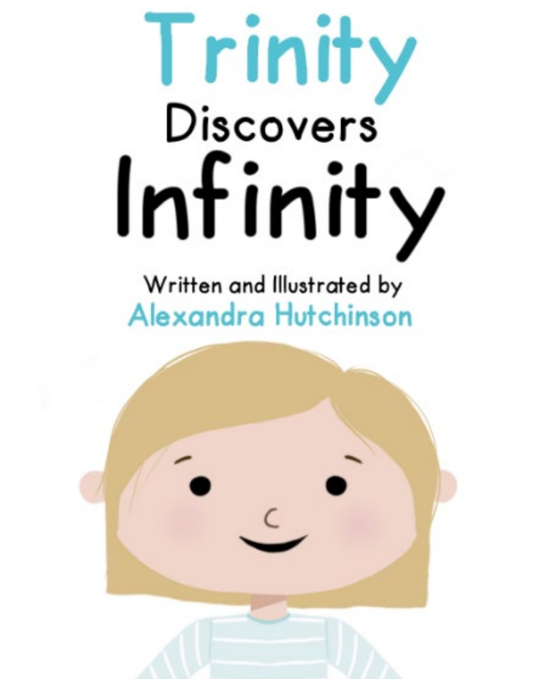
Chain Rule: When taking the derivative of a function within a function, take the derivative of the outside times the derivative of the inside.

Example: (d/dx) sin(2x)=cos(2x)(2)=2cos(2x) Example: (d/dx)(7+6x^2)^3=3(7+6x^2)^2(12x)=36x(7+6x^2)^2

The children's book is technically a document containing all the pages, including the cover, of a children's book (see Figure 13). This LO is full of illustrations for children with some texts to tell the story of a little girl meeting a mathematician.

Figure 13

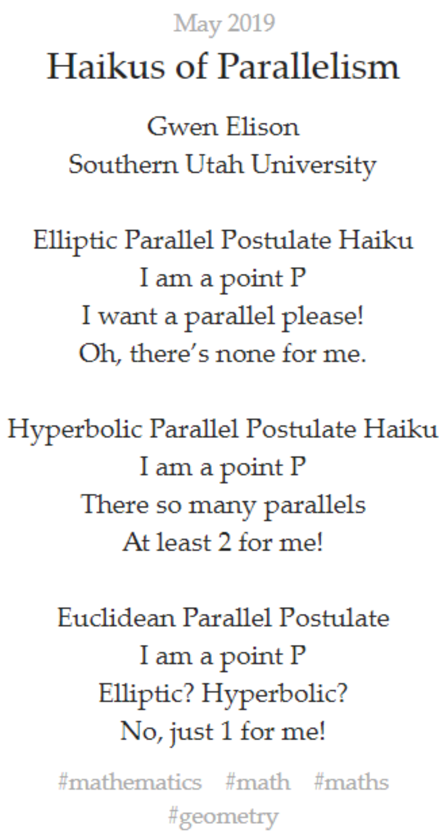
The Cover of a Children's Book LO



The LO categorized as a poem is a set of three haikus (see Figure 14). These three haikus are looked at as one LO because they describe the parallel postulates of Euclidean, hyperbolic, and elliptic geometries, and are meant to be used together.

Figure 14

A Screenshot of a Poem LO



May 2019

Haikus of Parallelism

Gwen Elison
Southern Utah University

Elliptic Parallel Postulate Haiku
I am a point P
I want a parallel please!
Oh, there's none for me.

Hyperbolic Parallel Postulate Haiku
I am a point P
There so many parallels
At least 2 for me!

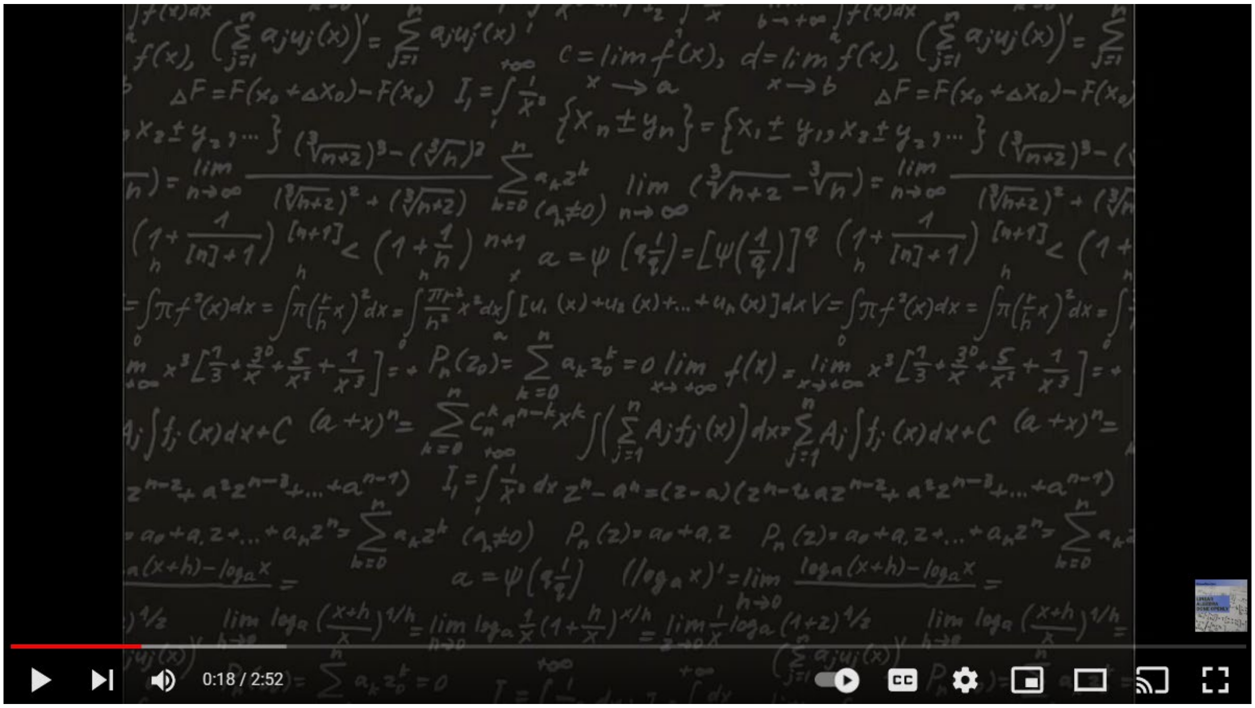
Euclidean Parallel Postulate
I am a point P
Elliptic? Hyperbolic?
No, just 1 for me!

#mathematics #math #maths
#geometry

The song in the dataset is technically a video described as a song. The visual component of this music video is only a static image (see Figure 15). The tune and lyrics of this calculus song are both written and sung by the student creators. It starts by giving a brief historical background of calculus, and gets into the concepts and rules for derivatives and integrals. The song then ends with some general applications of calculus in science.

Figure 15

A Screenshot of a Song LO



Stage of Learning

Next, I examined the stage of learning of each LO, and there were three that emerged from the analysis: *initial*, *subsequent*, and *terminal*.

Initial Stage of Learning. An LO that is designed for an initial learning experience is one that assumes no prior knowledge of the intended mathematics from its users. For example, a particular subset of the dataset is the PGP collection, which shows the highlighted text of the intended theorem with its associated figure step-by-step and side-by-side (see Figure 5). This subset is categorized as *initial* even though some theorems are taught after the others because each PGP introduces the intended theorem step-by-step as if the user has never seen the theorem before.

Another example of an LO designed for an initial learning experience would be a children's book that introduces the concept of infinity to children. This book tells a story of a little girl's encounter with Sir Isaac Newton. In the book, Newton helps the little girl understand that infinity is not simply a very big number, but a calculus concept related to limits. The little girl had never heard of calculus before, but was able to understand more about limits and infinity at the end.

Subsequent Stage of Learning. For an LO to be categorized as *subsequent*, it would mean that its intended users are expected to have some background knowledge on the intended mathematics. However, the users are not expected to have fully understood the mathematics yet. For example, the digital flashcards for exam preparation are categorized as *subsequent* because the flashcards provide a collection of theorems and formulas to know and/or memorize as if the users have seen those theorems and formulas before. Another example is a video about trigonometric substitution for integrals. The student-creator of this video spent only 30 seconds going through the three radical expressions for which trig substitutions are used ($\sqrt{a^2 - x^2}, \sqrt{a^2 + x^2}, \sqrt{x^2 - a^2}$), the three substitutions, and the three associated trig identities. The rest of the 15-minute video is spent on going through each step of an integration problem. This particular LO is categorized as *subsequent* because it provides a minimal amount of background knowledge related to trig substitution as a reminder instead of an introduction.

Another example of a *subsequent* stage of learning is the derivatives tutorial LO that is shown in the Data Analysis section. The same student creator also created another LO called integrals tutorial that is categorized as *subsequent*. This integrals tutorial LO demonstrates a lot of the procedures about evaluating an integral without much explanation of the symbol used, including the integration sign, the differential, or the relationship between f(x) and F(x) in the context of integration. Since these fundamental concepts related to the central idea are assumed to be known to the users, this LO is designed for a subsequent learning experience.

Terminal Stage of Learning. The last stage of learning is *terminal*. Instead of aiming to help the users to learn some unfamiliar mathematics, the LOs in this category give a context in which users can apply or appreciate mathematics they have already come to understand. One example of application is lesson plans created for teachers. Teachers do not use lesson plans to learn mathematics. Instead, lesson plans help teachers to apply the mathematics they have already mastered to their teaching. An example of appreciation is the set of 3 haikus about the parallel properties in Elliptic, Hyperbolic, and Euclidean geometry. The primary purpose of poems is not to teach, but to describe some idea in an aesthetic way. Through this LO, users that understand parallelism in different geometries can admire the mathematical concept in a beautiful format. Some other examples include a card game based on the axiomatic system of geometry, and a fun song about calculus. Jeopardy games are also included in this category because those LOs include only the answers for verification but not any explanation of the answers for student learning. The theme of the stage of learning is summarized in Table 2.

Table 2

The Count of Each Stage of Learning of the LOs in the Design Component

Stage of Learning	Count
Initial	22
Subsequent	8
Terminal	22

Potential Expert Improvement

Lastly, I examined the ways that an expert would likely improve a given student-created LO. As mentioned before, some aspects of the student-created LOs would need to have a level of quality similar to the existing resources in order to provide an added value. The determinations here are made based on comparison between the student-created LOs and the professionally created LOs available. Three types of possible improvements were identified: *content*, *form*, and *mechanics*.

Potential Improvement in Content. There are two ways in which an LO could be improved in *content*. The first is when multiple pieces of mathematics are put together without an explicitly given reason. For example, in a video tutorial LO about geometry, the construction of a regular n-gon and the impossible problem of squaring the circle were put together. An expert might not choose to introduce two separate topics that are not closely related in the same video in order to keep the LO focused on one central idea. Another example would be another video tutorial LO about trisecting an angle and doubling a cube. Although these two topics may seem connected to someone who is familiar with the mathematics, the LO does not explicitly connect the two problems for the intended users. Therefore, to the intended users, the two geometric constructions are just two disjoint problems.

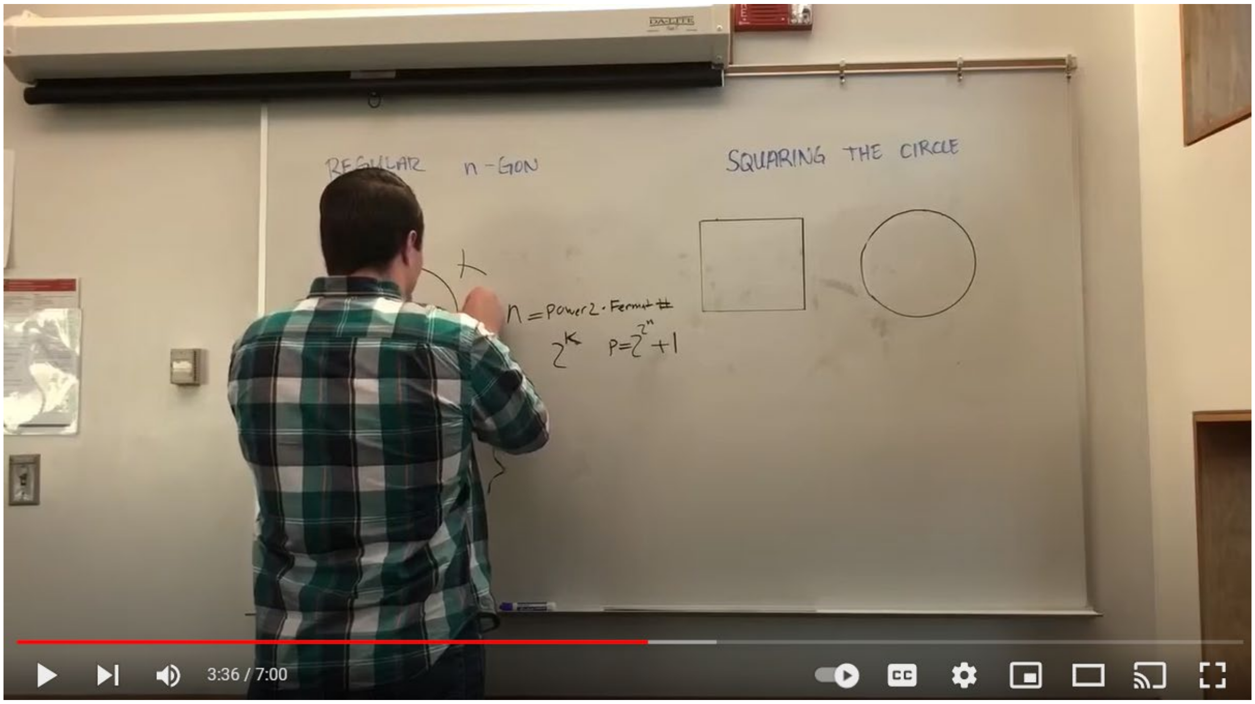
The second way an LO could be improved in *content* is when the LO is described as covering a wide range of mathematics but not everything described is actually covered. For example, a practice exam named "Comprehensive Calculus Exam" not including some important topics including trigonometric substitution and convergence tests for series. This LO gives the impression that it contains a comprehensive representation of calculus when that is not the case. As a result, users may think they have reviewed all Calculus topics when, in fact, they have not..

There are multiple ways students could choose the content to be included in an exam review. Some may only review content they understand, and others may review content they find challenging. Therefore it is unclear for what reason some topics are excluded from those LOs. In addition to that, since those reviews were created by students and not the teacher who would create the exam, the resemblance between those reviews and the actual exams would seem questionable.

Potential Improvement in Form. The *form* of an LO is not about its mathematical content, but its overall quality and presentation. Or, in other words, how professional an LO looks and feels. An LO that does not look and feel professional often distracts its users from its purpose. For example, there are multiple video LOs in the dataset that feature the student-creators' body or hands as they wrote or drew on a piece of paper or a whiteboard, which often block the users' view. Because of the obstructed view, users of the LOs are not able to follow algebraic manipulation or the geometric constructions of the LOs as the videos play (see Figure 16). An expert might choose to write the mathematics on a digital surface that could be better shown to the users without blocking their views. Another example would be making better use of mathematical typeface such as $\frac{dy}{dx}$ instead of dy/dx. Even though these issues may seem little, they are important when it comes to adding value to the many resources that already exist. The quality of this aspect of student-created LOs would still need to be similar to the quality of existing resources.

Figure 16

A Screenshot of a Video LO with an Obstructed View



Potential Improvement in Mechanics. The *mechanics* of an LO is about its functionality, or how well it performs as an object. There are only 3 LOs in the dataset that would likely be improved in *mechanics* by an expert, and all 3 LOs are games. Two of those were Jeopardy games that did not have a built-in scoring system. The remaining one is the Geometry Fluxx card game. The original Fluxx card game is a game where its rules change as the players play the game. Although the overall structure of Geometry Fluxx follows the original Fluxx card game, each player needs to construct a geometric model using points and lines in order to win the game. With game rules that change continually throughout the game, and a unique variation of constructing a geometric model, users of the LO could really benefit from some sample plays, but there are no sample plays in the rulebook.

No Potential Improvement. Out of the 52 LOs in the dataset, there are 14 that fall into the category of *none* when it comes to potential expert improvements, which means those LOs are at a similar level of quality as existing resources. And out of those 14, 11 were part of the PGP collection that was created as supplementary materials to the lecture notes of the geometry class. As mentioned before, each PGP highlights and goes through each sentence of one theorem. A PGP shows a highlighted sentence of a theorem alongside the associated figure, which helps the users to visualize the theorem they are learning. The *form* of the PGPs are also of high quality. All the texts are typewritten, and all the figures are drawn and shown clearly. Finally, the navigation of a PGP is simple and intuitive, with each click from the user, the LO proceeds from one sentence to the next.

One of the remaining 3 that are in this category of *none* is an appendix of the same lecture notes (see Figure 11) for the class where the renewable assignment was given. This LO uses an axiomatic system to describe the natural numbers. The intended users of this LO should be familiar with the structure of an axiomatic system through learning about the many geometries covered in the class, and this LO gives an alternate context of an axiomatic system that is not geometry. Furthermore, this LO looks and feels professional because it is created in the same style as the lecture notes, and it is seamlessly incorporated into the lecture notes. Also, the document performs as expected, as all the information is readable. Therefore, this LO is categorized as *none*. The last two LOs in this category are the poems about parallelism, and a children's book about infinity. The theme of possible expert improvement is summarized in Table 3.

Table 3

The Count of Each Potential Expert Improvement of the LOs in the Design Component

Functionality	Count
Content	14
Form	14
Mechanics	3
None	30

Other Observations. Lastly, it should also be noted that 8 of the LOs in the dataset fit into only one potential improvement category, 10 of them fit into two categories, and none of them fit into all three categories. Out of the 10 that fit into two categories, 9 of them could potentially be improved in both *content* and *form*. And 7 of those 9 were very similar in nature. They were all unscripted and lightly-edited videos that show the student creators talking and writing on a physical surface such as a whiteboard or a piece of paper. These LOs do not show a lot of planning or preparation with the users in mind, meaning they do not seem like they were created to help someone else learn. Instead, they feel like a mere demonstration of some mathematical knowledge of the student creators. In other words, these LOs might have some internal gravity (Seraphin et al., 2019), but are not really created for the use of learners.

Accuracy

The second component of usability is *accuracy*. In this component, I examined three themes: the accuracy in the student creator's description of an LO, the correctness of the mathematics in an LO, and the completeness of the mathematics in an LO.

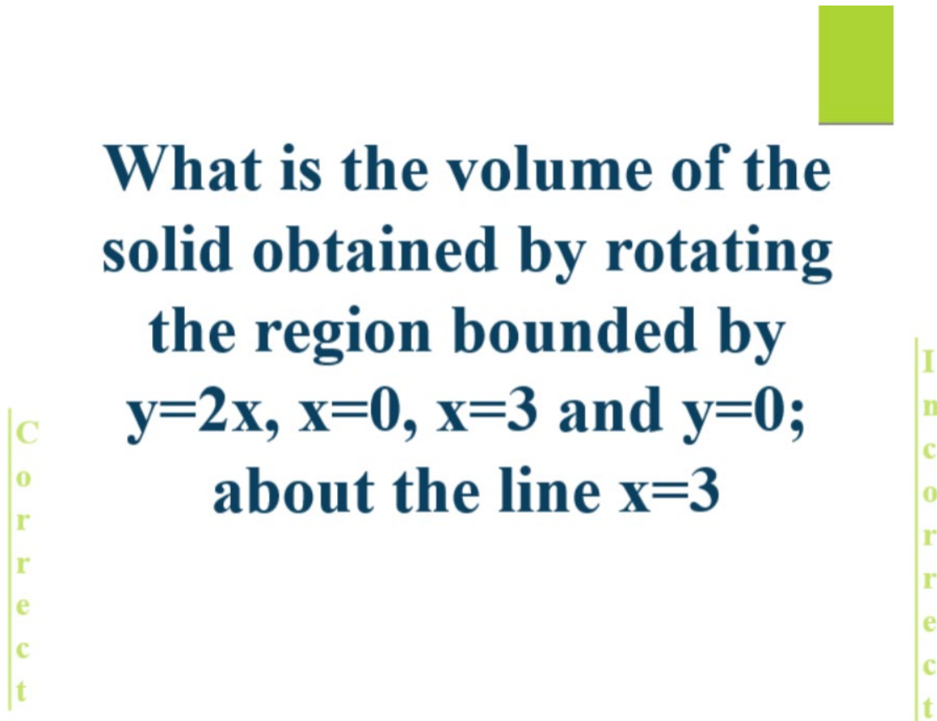
Title and/or Description Mismatch

One of the first impressions of an LO that its users get would be from reading its title and description. An accurately described LO would likely be able to attract its intended users. In the collection of 52 LOs, 42 of them do what their title and description suggest they would do. For example, an LO named "calculus song" is a song about calculus, and an LO that is described as a children's book is a book made for children. Eight of the LOs show a mismatch between their perceived purpose and what they actually do. One example is a video LO (Trigonometric Substitutions) that claims to give an in-depth explanation of trigonometric substitution but only goes over one problem involving the substitution without explaining why each of the three substitutions works for their corresponding radical expression.

Another example of a mismatch between the LO and its description is a Calculus Jeopardy game LO that is actually a collection of practice problems. In other words, instead of being given a description of some mathematical concepts and then answering "what is" followed by the name of the concept, users of the LO would be given a practice problem (see Figure 17) and then answer "what is" followed by a number. Thus, this Jeopardy game LO does not have questions in the form of an answer and answers in the form of a question similar to the special style of a typical Jeopardy game. In almost half of the questions, players are just asked to evaluate some mathematical expression (e.g., $\lim_{x\to 3}\frac{4x^2-2x+4}{3x+8}$, $\int_0^1\int_{x^3}^{\sqrt{x}} 4xy - y^3\,dydx$, $cos^{-1}\frac{\sqrt{3}}{2}$).

Figure 17

A Question in the Calculus Jeopardy LO



Some other examples of mismatch in description are lesson plans that were claimed to be created specifically for some particular mathematical tasks within a curriculum only focus on one specific core standard within the tasks instead of utilizing the tasks in their entirety as they claim to do. The problem here is that the description of the lesson plans gives an impression that they are an alternate way to provide instruction using the tasks. And the potential users would only discover less than half of a task is actually used in those LOs.

Mathematical Correctness

Mathematical correctness also affects an LO's usability. However, not all inaccuracies would have the same impact on the usefulness of an LO; some inaccuracies are more closely related to the central idea of an LO than others, and some inaccuracies are less noticeable to the intended users than others. Out of the 52 LOs in the dataset, 32 of them were free of any inaccuracies. The remaining 20 contained some mathematical inaccuracy.

Major Inaccuracy. An inaccuracy that is closely related to the central idea of the LO, and is not likely to be resolved by its users is categorized as a *major* inaccuracy. For example, in a collection of digital flashcards that is supposed to help its user to memorize equations that might be needed for an exam, all of the coefficients for quadric surfaces ($\frac{1}{a^2}, \frac{1}{b^2}, \frac{1}{c^2}$) were missing. Since the potential users of this LO likely use the flashcards to help them memorize facts that they need to recall on an exam, incorrect information on these flashcards would seriously reduce the effectiveness of this LO. Another example of a major inaccuracy is found in an LO that is a practice exam. When it comes to the limit definition of a derivative, its answer key used $f(x) + h$ instead of $f(x + h)$. The answer key of a practice exam is used for students to judge their own performance and, in some cases, students may even study the answer key to learn a typical way to solve a problem. Having inaccuracies in an answer key could really mislead students that are trying to evaluate their understanding of the material, especially when the inaccuracy looks so similar to the correct answer. There are 6 LOs in the dataset that contain a *major* inaccuracy.

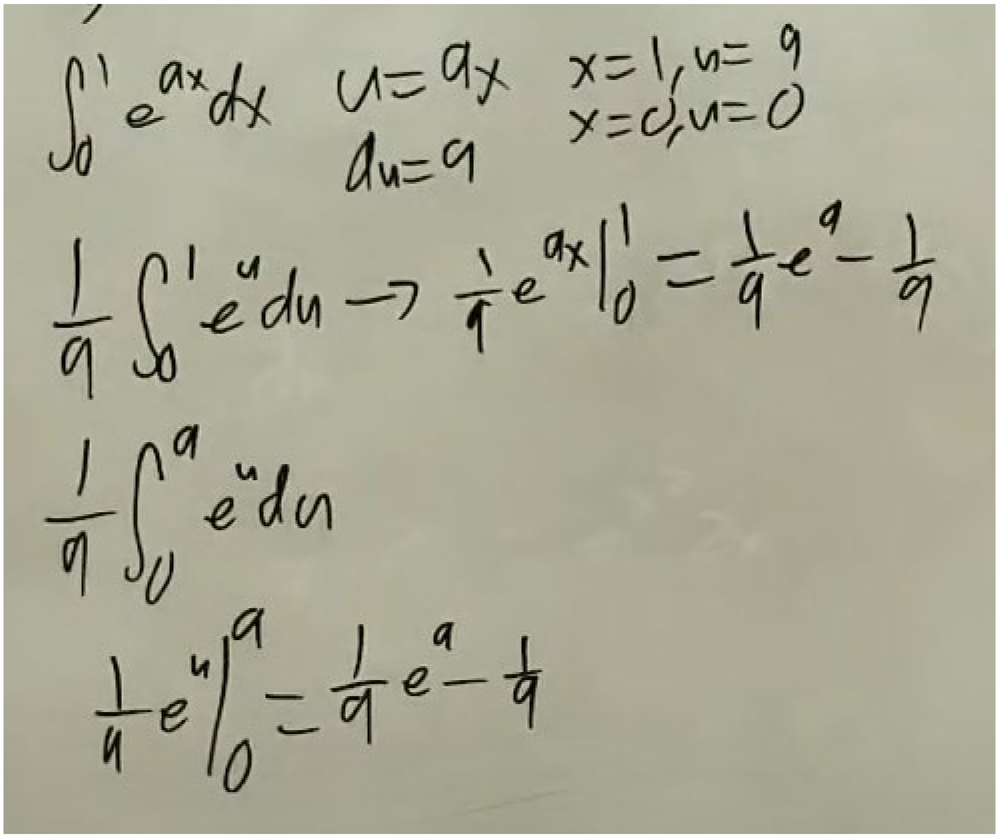
The remaining 14 LOs contain inaccuracies that either are not closely related to the central idea of the LO, or could reasonably be resolved by its users. These inaccuracies are categorized as *minor*.

Peripheral Inaccuracy. One reason a inaccuracy is considered minor is if it is not closely related to the LO's central idea. For example, in an LO that is supposed to introduce its users to derivatives, some examples of partial derivatives were included as a little preview of multivariable calculus. And one of those examples had mistakenly used a positive sign instead of a negative sign. This inaccuracy is considered peripheral because it was not about single-variable differentiation, which is the central purpose of the LO. Therefore, the intended users of this LO are not likely expected to be actually learning multivariable calculus and thus likely would not be as affected by this inaccuracy. There are 5 LOs in the dataset that have *peripheral* inaccuracies.

Inaccuracy with Multiple References. Another reason an inaccuracy is considered minor is if the inaccuracy is represented correctly elsewhere in the LO. For example, in one of the PGPs, an angle was mislabelled in the text of the proof, but the figure of the proof had it labeled correctly. Another example is an exam prep LO named "Review of Calc 1," which is shown in Figure 18. In this LO, the student-creator demonstrates how to use u-substitution to solve a definite integral. The student creator shows both changing the bounds of integration to be in terms of u and rewriting the u in the anti-derivative to be in terms of x in the demonstration. All of the bounds of integration implicitly refer to the correct variable of integration, except for the bounds on the integration sign that is second from the top. Given the many correct references and the verbal explanation of the student creator, this inaccuracy is considered minor. Compared to misrepresenting a mathematical concept entirely, LOs in this category are less negatively impacted because the concept is referenced multiple times and some of those references were correct. There are 4 LOs that fall into this category of *multiple references*.

Figure 18

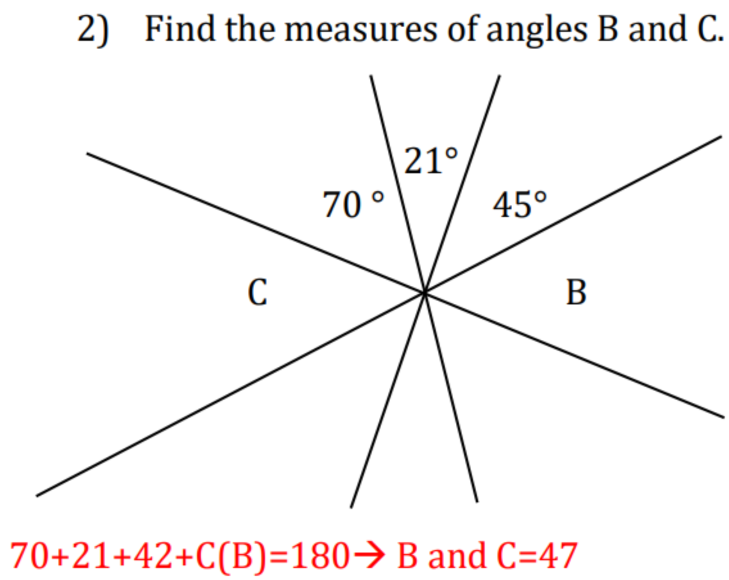
A Partial Screenshot of the LO Review of Calc 1



Inaccuracy Reviewed by Expert. Lastly, an inaccuracy is also considered minor if the LO is meant to be used by someone who would be teaching or using the mathematics instead of learning it. In such cases, even though the inaccuracies in the LOs would likely be noticable and correctable by the users, the inaccuracies might still be somewhat problematic. For example, two inaccuracies in a lesson plan about supplementary angle comes from a figure and its associated statement $70 + 21 + 42 + C(B) = 180 \rightarrow B \text{ and } C = 47$ (see Figure 19). The first one is the discrepancy between the 45 in the figure and the 42 in the statement. It's more likely that the 45 is supposed to be a 42, or else the answer would also need to be adjusted. The second one is about the statement that looks to have used a parentheses notation to indicate that C could be replaced with B in the equation. Even though multiplying C and B would cause a mistake here, this inaccuracy is considered minor because teachers would likely be sufficiently familiar with the meaning of supplementary angles to recognize that multiplying two angle measures does not make sense here, so there is a misuse of notation.

Figure 19

Part of a Lesson Plan LO



Another example is a Calculus Jeopardy LO where one of the questions is "Evaluate the integral $\int_2^6 5\,dx$. Instead of the correct answer "What is 20?", an incorrect answer of "What is 2?" is given in the LO. Even though there is a typo, since this game is likely to be used by a group of students that have already learned the mathematics, or possibly with a teacher or a host that is an actual expert of the mathematics, this inaccuracy would likely be noticed and corrected by the users. All 5 LOs that fall into this category of *reviewed by expert* were previously categorized as created for a *terminal* stage of learning where certain inaccuracies are not as impactful because the intended users should be familiar with the mathematics enough to notice and correct the error. For example, teachers preparing to teach a lesson should be able to spot the errors in a lesson plan.

It should also be noted that there were no overlaps among the three minor categories for inaccuracies. Thus none of those LOs contained multiple types of minor inaccuracies.

Mathematical Completeness

Mathematical completeness is the last theme within the component of *accuracy*. An LO is categorized as incomplete only when the incompleteness significantly impacts its value to its users, or when the incompleteness is severe enough to keep its users from its central purpose. Out of the 52 LOs in the dataset, 18 were considered incomplete. The remaining 34 were considered complete.

Incomplete Structure. One reason an LO is considered incomplete is if some relevant mathematics is excluded from it. For example, in the LO about derivatives shown in the Data Analysis section, all of the common differentiation rules (power rule, product rule, quotient rule, etc.) were covered except for the sum and difference rules. Similarly, an LO is also said to be incomplete if some irrelevant mathematics is included in it. For example, in an LO that reviews calculus I, integration by parts was included when it is a topic typically found in calculus II, not in calculus I. Also, integration by parts is found in the professor's lecture notes for calculus II only. Including something that is not part of the described scope of the LO may mislead the users to believe that they have seen a complete picture of the mathematics when they have not. Both types of incompleteness in this paragraph, excluding something that should be part of the content of the LO and including something that should not be part of the content of the LO, are categorized as *incomplete structure*.

Incomplete Explanation. Another reason an LO is considered incomplete is if some relevant mathematics is mentioned in an LO but not sufficiently explained to its users. For example, in an LO about why it is impossible to trisect an angle or square a circle using a straightedge and a compass, the meaning of those geometric constructions were explained. But the explanations of the impossibility of those constructions were built on the unexplained idea of an inconstructible number. The student creator simply gave the form of an inconstructible number and used algebra to show that the number needed for those geometric constructions is an inconstructible number. Another example is an LO about Fano Geometry. After presenting the axioms of the geometry and building a model for it at the same time, the student creator claimed that the model built is the only model of the geometry "up to isomorphism" without any further explanation of the term and its meaning in the context of the LO.

Incomplete Usage. All 4 LOs that were categorized as *incomplete usage* were lesson plans. More specifically, lesson plans that were claimed to be created for existing tasks without any modifications. Instead of utilizing the entirety of the tasks as they claim to do, those four lesson plans guide their users through only parts of the tasks that fulfill a specific standard that the lesson plan was set out to accomplish.

For example, one lesson plan uses only 2 of the 7 questions in the task during class, and the remaining 5 are assigned as homework to the students. The purpose of this particular task is about proving and understanding that all circles are similar. Most of the skipped questions explicitly ask students to explain their reasoning as they explore the different features of a circle. One of those questions asks students why they may think the ratio between the length of the circumference to the length of the diameter is the same across all circles. Discussion questions of this nature can be a lot more beneficial to students when used in groups compared to individually. This is categorized as *incomplete usage* because the questions in the task are designed to promote student learning by bringing about a conversation among the students and with the teacher. There is no indication in the lesson plan on when and how the teacher should follow up on those 5 questions. Thus, the lesson plan incompletely uses the task.

Another example of incomplete usage is a lesson plan that references only some of the figures in a task while completely disregarding all the text and intention of the task. The original task is designed to help students explore the relationship between the different features of a triangle and its inscribed and circumscribed circles, such as inscribed angles, radii, and tangent lines. The task then extends those relationships to quadrilaterals inscribed in a circle. The task starts by giving students three scalene triangles and asks students to find the circles that inscribe those triangles using a compass and a straightedge. It then continues to have students go through seven more exploratory questions to solidify and extend their understanding. By contrast, the lesson plan is only designed to cover the construction of inscribed and circumscribed circles of triangles. The lesson plan states that students should receive the page of the task containing the 3 scalene triangles, and be asked to find the centroid and incenter of each of the 3 triangles. The rest of the lesson plan asks students to share their construction of the centroid and incenter, list property of the two special points, and construct the inscribed and circumscribed circles using those two special points for each triangle. In short, the lesson plan takes the starting point of the task, expands it, and turns it into a standalone lesson. The only connection between the lesson plan and the task is the construction of an inscribed circle of each of the three scalene triangles, which is almost trivial. Therefore, the lesson plan does not actually use the task as it claims.

The *accuracy* category is summarized in Table 4. It should also be noted that there were no overlaps among the three categories for incompleteness. It is because none of those LOs contained multiple types of incompleteness.

Table 4

The Count Distribution within the Accuracy Component

	Mathematical Correctness				Mathematical Completeness		
Title and/or Description Mismatch	Major Inaccuracy	Peripheral Inaccuracy	Inaccuracy with Multiple Reference	Inaccuracy Reviewed by Expert	Incomplete Structure	Incomplete Explanation	Incomplete Usage
8	6	5	4	5	6	8	4

Visibility

The last component of usability is *visibility*. In this component, two themes were examined: whether an LO shows up in a Google search, and whether it shows up in a search on its host platform. The vast majority of the LOs did not show up in the first three pages of a Google search results using keywords that someone would likely use if they are searching for resources similar to the LO. In other words, it is unlikely that someone would come across most of the LOs in the dataset through a Google search. On the other hand, if an LO shows up early in a list of the search results, then it is a lot more likely that someone might use it. Out of the 52 LOs in the dataset, 50 fall into this category of *not likely to come across*.

Google

There are 2 LOs in the dataset that did show up in the first three pages of the Google search results. One of the two that shows up is a video about Fano Geometry. The total number of return results for a search on *"Fano Geometry"* is 6,350, and the LO shows up as the second video result on the first page. A possible reason this LO shows up could be because Fano

Geometry as a topic is not extremely popular, and so there are not as many resources about Fano Geometry available online. The other LO that shows up in a search is a video of a proof of the alternate interior angle theorem. A search with the phrase *"alternate interior angle theorem" proof* returned 7,310 results, and the LO shows up as the third video result on the first page.

It should be noted that there are two collections of LOs in the dataset that each exist online as a collection and could reasonably be searched for as a collection. One of the two is the collection of 13 lesson plans that cover the geometry standards in the Utah core of integrated secondary mathematics II; the other is the collection of 11 *PGPs* covered in the course the student creators were taking. When a search is done for the lesson plans as a collection instead of as individual LOs, with the search phrase *utah secondary math II "lesson plans" geometry*, the collection of lesson plans shows up third out of 775,000 results. A possible reason that these LOs show up so early in the search results could be they are a sizable collection. However, the collection of geometry proofs did not show up even when a search for the collection was done.

Host Platform

Even though most of the LOs in the dataset do not show up early on a Google search, there are other ways in which people could come across those LOs. Most specifically, all the LOs in the dataset are either hosted or referenced on the website of the professor who assigned the renewable assignment to the student creators. For the LOs whose intended users are the future students of the same professor, it is reasonable to assume being hosted on the professor’s website is sufficient in terms of reaching the intended users.

On the other hand, there are other LOs whose intended users are anyone that is interested in some particular topics in mathematics referenced on the professor’s website but hosted on some other online platform such as Youtube (https://www.youtube.com) or

TeachersPayTeachers (https://www.teacherspayteachers.com). In addition to a Google search, one of these LOs may come up if someone searches for it on the platform where it is hosted. For example, someone may come across a video LO while searching for resources similar to it on Youtube. Out of the 52 LOs in the dataset, 36 of them exist on a searchable host platform. A search for each of those 36 LOs on its host platform was done to see whether it is likely for someone to come across those LO while searching within that subset of the internet. The 2 LOs that showed up on a Google search also showed up in a search on their host platform. The same 13 lesson plans that showed up as a collection on a Google search also showed up as a collection on their host platform. In addition to that, 7 of those 36 showed up within the first three pages of the search results, which makes it likely for someone to come across them if they were searching on those host platforms. For example, 5 of the 9 LOs were lesson plans that were uploaded to TeachersPayTeachers by the student creators, which allows users to filter search results by price and resource types. Once a search is done with common filters applied (i.e., free and lesson plan), the number of results is reduced to 60 or less and the LOs could be found within the first three pages of the results. Three of the other 4 LOs that showed up in a search were videos on Youtube, two of which are the ones that showed up on a Google search. And the last LO was a set of flashcards on Quizlet. Since the remaining 14 LOs did not show up, it is unlikely that someone would come across them on their own even if a search is done on the specific host platform (see Table 5).

Table 5

The Count Distribution within the Visibility Component

	Google (N=52)	Host Platform (N=36)
Show Up Individually	2	9
As a Collection	13	13
Not Show Up	37	14

Discussion

Before I begin the discussion of the results of this study, it is important to note the difference between this study and the two other studies in the Literature Review section that are also about the usability of student-created LOs (Croft et al., 2013; Jordan et al., 2016). Unlike the two other studies, this study does not measure the impact these student-created LOs have on other students' performance. The purpose of this study is to explore the nature of the potential value these LOs have to the intended users. By qualifying the different aspects of an LO that could affect its usability, we may begin to understand how student-created LOs could "provide a lasting benefit to the broader community of learners" (Wiley & Hilton, 2018, p. 137).

Figure 20 is a summary of the analysis results. A cross in a cell means there is a deficiency within the LO on that row in the category in that column. LOs whose row contains more crosses have a lower usability, and LOs whose row contains fewer crosses have a higher usability. Overall, there is a varying level of usability among the LOs in this dataset. There are several LOs with just a couple of issues, a few LOs with a few issues, and some LOs with a lot of issues. Some of the better LOs in this dataset include the PGPs, some of the lesson plans, the classroom activity, the appendix to the lecture notes, video tutorials about the alternate interior angle theorem and Fano geometry, the children's book, and the poems. One other observation worth noting is that, in general, the LOs created by students in the Calculus III class seem to have more issues than the LOs created by students in Modern Geometries.

Figure 20

A Summary of the Results

	Design					Accuracy								Visibiliy	
	format	stage of learning	functionality				correctness				completeness				
		i: initial s: subsequent t: terminal	problematic content selection	improper form	mechanical issue	title/description mismatch	major mathematical error	peripheral error	multiple references	reviewed by expert	incomplete structure	incomplete explanation	incomplete usage	Google	Host platform
Secondary Math II Geometry Lesson Plan 7.5	lesson plan	t												(x)	(x)
Secondary Math II Geometry Lesson Plan 7.2	lesson plan	t				x							x	(x)	(x)
Secondary Math II Geometry Lesson Plan 7.3-1	lesson plan	t				x							x	(x)	(x)
Secondary Math II Geometry Lesson Plan 5.6	lesson plan	t												(x)	(x)
Secondary Math II Geometry Lesson Plan 5.7	lesson plan	t											x	(x)	(x)
Secondary Math II Geometry Lesson Plan 7.3-2	lesson plan	t				x								(x)	(x)
Secondary Math II Geometry Lesson Plan 7.7	lesson plan	t												(x)	(x)
Secondary Math II Geometry Lesson Plan 5.9	lesson plan	t				x							x	(x)	(x)
Secondary Math II Geometry Lesson Plan G6.3	lesson plan	t				x								(x)	(x)
Secondary Math II Geometry Lesson Plan 6.6	lesson plan	t												(x)	(x)
Secondary Math II Geometry Lesson Plan 6.3	lesson plan	t								x				(x)	(x)
Secondary Math II Geometry Lesson Plan 6.4	lesson plan	t												(x)	(x)
Secondary Math II Geometry Lesson Plan 6.3	lesson plan	t												(x)	(x)
7th Grade Geometry Lesson Plan	lesson plan	t	x							x				x	
9th Grade Triangle Congruence and Similarity Lesson Plan	lesson plan	t								x				x	
Transformations Lesson Plan	lesson plan	t								x		x		x	
Triangle Congruences	classroom activity	t												x	
Progressive Geometry Proof 1.3.14	visual aid	i					x							x	-
Progressive Geometry Proof 2.4.9	visual aid	i												x	-
Progressive Geometry Proof 2.4.19	visual aid	i												x	-
Progressive Geometry Proof 3.2.6	visual aid	i												x	-
Progressive Geometry Proof 3.3.5	visual aid	i												x	-
Progressive Geometry Proof 3.5.3	visual aid	i												x	-
Progressive Geometry Proof 3.6.10	visual aid	i												x	-
Progressive Geometry Proof 4.2.2	visual aid	i												x	-
Progressive Geometry Proof 6.4.2	visual aid	i												x	-
Progressive Geometry Proof 6.4.3	visual aid	i												x	-
Progressive Geometry Proof 6.8.5	visual aid	i							x					x	-
Peano's Axioms	lecture notes	i												x	-
Regular n-gon & Squaring the Circle	video tutorial	i	x	x										x	x
Trisecting an Angle & Doubling a Cube	video tutorial	i	x	x								x		x	
Circumscribing and Inscribing a Triangle	video tutorial	i	x	x										x	x
Perpendicular Bisector of a Line & Bisecting an Angle	video tutorial	i	x	x					x			x		x	x
Fano Geometry	video tutorial	i		x								x			
Supplements of Congruent Angles are Congruent	video tutorial	i		x										x	x
The Alternate Interior Angle Theorem	video tutorial	i		x											
The Midpoint Theorem	video tutorial	i		x										x	x
Derivatives Tutorial	video tutorial	s	x	x				x			x			x	x
Integrals Tutorial	video tutorial	s	x	x			x					x		x	x
Trigonometric Substitutions	video tutorial	s				x						x		x	x
Learning to Derive	tutorial	i	x	x				x				x		x	-
Exam 1 Review	exam prep	s	x				x				x			x	-
Comprehensive Calculus Exam	exam prep	s	x				x				x			x	
Review of Calc 1	exam prep	s	x	x					x		x			x	x
Calculus III Flash Cards	exam prep	s	x			x	x				x			x	
Exam 2 Study Materials	exam prep	s	x					x			x			x	-
Geometry Fluxx	game	t		x	x				x					x	-
Calculus Jeopardy	game	t			x	x				x				x	-
Geopardy	game	t			x		x							x	-
Trinity Discovers Infinity	children's book	i						x						x	-
Haikus of Parallelism	poem	t												x	-
Calculus Song	song	t	x	x				x				x		x	x

Note. The symbol (x) in the Google column indicates the LOs show up only as a collection. LOs from the Calculus III course are in the shaded rows. The other rows are LOs from the Modern Geometries course.

Based on the lack of crosses on the rows of the PGPs and Peano's axiom, LOs created as an extension of course materials seem to have a higher usability compared to the rest of the LOs. This is likely a result from the fact that the intended user of those LOs is the same professor that oversaw the creation process. Perhaps those student creators received more direction during the process and/or their products were held to a higher standard. On the other hand, there is one type of LO that seems to have a lower usability compared to the rest of the LOs, which is a non-scripted video showing the student creators writing, either on a piece of paper or on a whiteboard, and talking about some mathematical concepts. These are the video tutorial LOs that have crosses in *content* and *form*. This kind of LO could be beneficial to the student creator as it is an opportunity for them to present their understanding. However, the mathematical content on these videos are not always easy to see because the users' view is sometimes blocked by the student creator's hand or body. The presentation of the mathematics is also somewhat difficult to follow because of the nature of real time non-scripted human speech coupled with the fact that the student creators usually do not have an expertise in verbally presenting mathematics.

I now discuss observations about each of the three components of usability: *design*, *accuracy*, and *visibility*. In the first component of *design*, there seems to be a relationship between the stage of learning of the intended users of the LO and the 4 types of potential expert improvements. If we exclude the LOs created specifically as an extension of the course materials, we see that LOs created for initial and subsequent stages of learning are more prone to multiple types of potential expert improvements (1.90 and 1.75 on average respectively) than LOs created for a terminal stage of learning (1.09 on average). Although it is difficult to draw a statistically sound conclusion here, it is reasonable to suspect this is the case partly because those student creators do not yet have the skills to introduce brand new or relatively new mathematical topics to other learners. Another possible reason could be related to the fact that only one of the 12 LOs created for a terminal stage of learning is found to have potential expert improvement in content selection. The terminal LOs in this dataset seem to have a narrower focus compared to the initial and subsequent LOs. And as a result of the narrow content focus, not as much content selection is needed compared to an LO that covers a broader topic. Also related to the theme of possible expert improvement, only 3 LOs out of the entire dataset had a mechanical issue, all 3 of which were only missing some helpful feature that one might expect. This finding shows that this student population is capable of using technology to create LOs that operate as intended.

In the component of *accuracy*, the biggest observation is that there are not that many mathematical inaccuracies in the LOs. In other words, most of the LOs are mostly correct. It is important to note that about half of the LOs focus on content that is considered prerequisite to the course the student creators were in. For example, students in Calculus III creating an LO for Calculus I, and students in Modern Geometries creating an LO for high school geometry. However, this observation may still be somewhat surprising considering the fact that the student creators were novices in the mathematical content of the other half of the LOs.

In the last component of *visibility*, it was shown in the previous section how unlikely it is for someone to come across an LO through a Google search. This is especially true for LOs that cover a topic that is broad and common such as derivatives or integrals. There are already many high-quality resources online with various scopes that are freely available to anyone for virtually any general purposes. On the other hand, an LO created to extend the current curriculum, such as the PGPs, does not need to rely on showing up on a search for its potential value to be realized. Since the curriculum being extended is already used by the teacher, there are already users almost guaranteed to use the LOs because those LOs are incorporated into the course materials.

As a result, the student creators of those LOs would not need to worry about increasing the visibility of their LOs because the intended users would have access to them through the class, such as on the class website or the learning management system that hosts the class material.

Furthermore, student creators that choose to extend the curriculum do so likely because they have identified a way to improve the curriculum specific to their own interaction with it as a student in that class. Similar to a finding in the study of Croft et al. (2013), these areas of improvement are identified by the students because of their own struggle with the curriculum and could act as a scaffold to better facilitate the understanding of their peers.

CHAPTER 6: CONCLUSION

Wiley and Hilton (2018) proposed one of the qualifications of an LO created for a renewable assignment is the existence of an educational value to others (see Figure 1). Based on this single collection of LOs, we see that the level of educational value, or usability as defined in this study, could vary. Even though all of the LOs demonstrated some theoretical value to others, meaning someone could benefit by using the LOs in some ways, it is clear that some LOs are more usable than others. For example, most of the PGPs are free of any inaccuracies and provide a professional-looking visual representation of the theorems used in a class where the intended users are the students. Similarly, the Peano's Axioms appendix provides an accurate alternative context of an axiomatic system in the same style of the lecture notes. Moreover, compared to some of the video tutorials that seem to be a mere demonstration of the student creator's mathematical knowledge, the PGPs and the appendix seem to have been created truly with the intended users in mind. In other words, the PGPs and the appendix seem to have more "value beyond supporting [the student creators'] learning" (Wiley & Hilton, 2018, p. 137). Some other examples of LOs that truly seem to have the quality of an "authentic assignment" (Wiley & Hilton, 2018, p. 137) include the Geometry Fluxx card game, the children's book, and the poems. The card game allows its users to flexibly apply their knowledge of axiomatic systems in a fun way. The children's book uses a simple story line and language to communicate with its intended users and is filled with beautiful illustrations. And the poems show a fresh take on mathematics by presenting it in a medium not traditionally used for mathematics.

Therefore, it is evident that the simple existence of a potential value does not guarantee that an LO lives up to the vision of a renewable assignment, which is to "provide a lasting benefit to the broader community of learners" (Wiley & Hilton, 2018, p. 137). Furthermore, despite some of the good qualities in the *design* and *accuracy* components of some of the LOs, not all of them seem to have a practical value to others because of low *visibility*. Given how unlikely it is for someone to actually find them, let alone use them and benefit from them, the potential value of these LOs likely would never turn into practical value. In other words, the existence of a potential value of an LO says very little about its practical value. This matters because a reason students find renewable assignments meaningful is their belief that their LOs could actually help others (Allan et al., 2017). Therefore, if an educator wishes to implement renewable assignment into their practice and help their students bring value to the broader community, they should look beyond the simple existence of some usability in the LOs and aim to create LOs with practical value to others. Some suggestions to promote practical values of student-created LOs through renewable assignments are included in the following paragraphs.

First, incorporating a peer review into the process of the renewable assignment could easily improve the usability of the LOs. Even a simple and correctable mistake in an LO could turn potential users away from it. And, understandably, given the time constraint every teacher faces, it is difficult for any one teacher to notice and give feedback on all the inaccuracies in dozens of LOs that take many different forms. However, the fact that there were not that many mathematical inaccuracies shown in the LOs is evidence that novice students are capable of ensuring the mathematical accuracy of the LOs. Therefore, a peer review could help students increase the accuracy of each other's LO and make the LOs more likely to be used. In addition to that, peer feedback could also help student creators to reflect on their own LO from the perspective of a user before submitting the final product.

Second, both the teacher and the students may get more out of the renewable assignment if the LOs are created to supplement the current curriculum (e.g., the Progressive Geometry

Proofs, Peano’s axiom as an appendix to the lecture notes). By capitalizing on this opportunity, the teacher continually receives a form of feedback on the curriculum from students that is easily applicable because the students would be creating the LO that potentially improves the situation. On the other hand, this approach would allow students to work within a context that is more focused, familiar, and well-defined to create something to help future students of the same class. In a certain way, the student creators would be creating the LO for their recent past self when they went through the same curriculum as they extend the curriculum. For example, students could create an LO that demonstrates an application of some relevant mathematics in a context that is relevant to them and possibly future students. That way, student creators can worry less about pedagogical issues and focus more on sharing their own experience as a user of the mathematics. As a result, students could be even more engaged and motivated by having a clearer vision of their final product. Furthermore, using LOs to extend the curriculum could be particularly useful if the curriculum is also openly licensed. By using a curriculum that is openly licensed, teachers can have complete ownership of a copy of the curriculum. That way, any extensions or modifications to the curriculum could be put into effect quickly and easily by the teachers. As a result, future students are guaranteed access to the LOs.

Third, students should incorporate their personal interests into the LOs. As mentioned above, the card game, the children’s book, and the poems seem to be more authentic than the other LOs. Unlike the skill of using a video, a document, or a slideshow to present mathematics, the skill of creating a card game, a children's book, or poems for mathematics seem to be outside of the typical skillset of a mathematics student. Therefore, it is likely that those student creators have a personal interest in card games, children’s books, and poetry, which allow them to understand the structure of those formats well enough to use them for mathematics. By incorporating a personal interest into a mathematics LO, students would be more invested in the creation process of the LO, and may be able to create an LO that is more unique than traditional learning resources.

Fourth, teachers should plan on taking advantage of the renewable aspect of the LOs. One of the unique strengths of implementing renewable assignments is that the LOs are openly licensed, which implies anyone could make changes to those LOs without having to worry about copyright issues. Moreover, students can renew LOs created by previous student creators as an alternative way to complete the assignment, as opposed to creating a new LO from scratch that may not hold much practical value. As shown in this study, there are ways that the student-created LOs could be improved. By actually renewing some of those LOs, students can help those LOs come closer to bringing practical value to the broader community. In other words, by renewing those LOs, we can help past and current students to keep the time and effort they put into the renewable assignment from being disposable (Wiley, 2013).

To conclude, there is evidence that student-created LOs in mathematics can bring value to a broader community. To increase the likelihood that an LO would actually be used, however, teachers may need to focus the students' effort to fill a specific need in the course that the students identified. This would help students create an LO that is more user-specific because of their own recent learning experience in the same course. Moreover, students can be more confident that the intended users of their LOs would come across the LOs because the intended users are future students taking the same course from the same teacher. In short, there is a trade off between the likelihood of the value of the LO being realized and the broadness of the community that could potentially benefit from the LO. And it may be more practical to help students bring value to a community, through renewable assignments, that they are more familiar with than one that is too broad.

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