Transition of an Interactive, Hands-on Learning Tool to a Virtual Format in the Covid-19 Era

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Transition of an Interactive, Hands-On Learning Tool to Virtual Implementations in the COVID-19 Era

Abstract
The 2020 coronavirus pandemic necessitated the transition of courses across the United States from in-person to a virtual format. Effective delivery of traditional, lecture-based courses in an online setting can be difficult and determining how to best implement hands-on pedagogies in a virtual format is even more challenging. Interactive pedagogies such as hands-on learning tools, however, have proven to significantly enhance student conceptual understanding and motivation; therefore, it is worthwhile to adapt these activities for virtual instruction. Our team previously developed a number of hands-on learning tools called Low-Cost Desktop Learning Modules (LCDLMs) that demonstrate fluid mechanics and heat transfer concepts—traditionally utilized by student groups in a classroom setting, where they perform qualitative and quantitative experiments and interactively discuss conceptual items. In this paper we examined the transition of the LCDLM hands-on pedagogy to an entirely virtual format, focusing on a subset of results with greater detail to be shown at the ASEE conference as we analyze additional data. To aid the virtual implementations, we created a number of engaging videos under two major categories: (1) demonstrations of each LCDLM showing live data collection activities and (2) short, animated, narrated videos focused on specific concepts related to learning objectives. In this paper we present preliminary results from pre- and post- implementation conceptual assessments for the hydraulic loss module and motivational surveys completed for virtual implementations of LCDLMs and compare them with a subset of results collected during hands-on implementations in previous years. Significant differences in conceptual understanding or motivation between hands-on and virtual implementations are discussed. This paper provides useful, data-driven guidance for those seeking to switch hands-on pedagogies to a virtual format.

Introduction
It is well known that the use of pedagogies which promote active learning, that is, learning where students engage with materials, rather than just passively receive information, promote improvements in academic performance and student attitudes [1, 2]. Chi developed the ICAP framework to further characterize active engagement into three distinct engagement modes: active, wherein students *manipulate* lecture materials rather than passively receive them; constructive, wherein students *generate* new knowledge using presented materials; and interactive, wherein students construct new knowledge through back and forth discussion and *exchange of ideas with peers* [3]. Chi postulates that interactive engagement promotes the deepest conceptual understanding; interactive engagement has indeed been shown to be superior to other forms of active learning for promoting knowledge gains [4, 5]. These results have inspired our team to create a number of low cost desktop learning modules (LCDLMs), which demonstrate fluid mechanics and heat transfer principles and were used in traditional undergraduate engineering classrooms to promote quantitative experimentation and interactive exploration of associated concepts. The use of these modules in small-group settings has been

shown to promote improvements in conceptual understanding compared to traditional lecture [6-8] and they have since been distributed to dozens of institutions across the United States as part of a large NSF IUSE grant effort. Figure 1 shows hydraulic loss and double pipe heat exchanger LCDLM kits, both small enough to fit on a standard desk and highly visual.

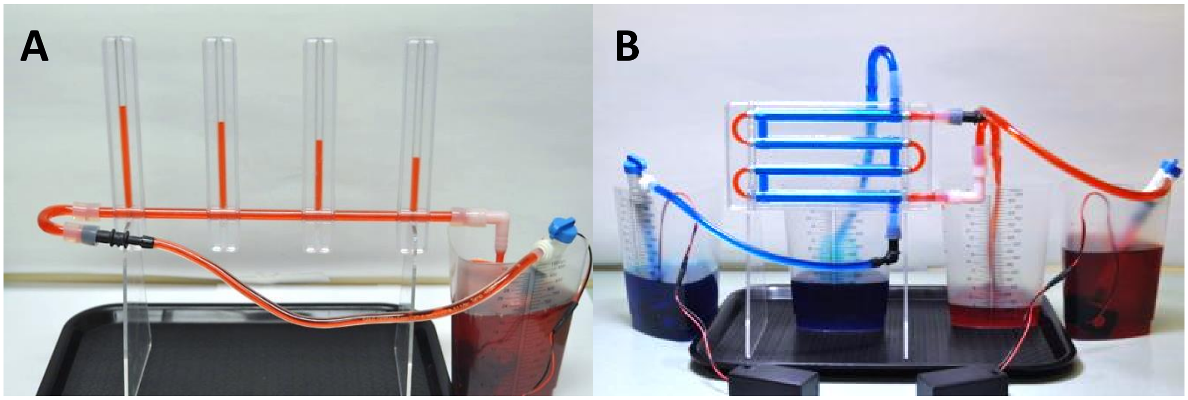

Figure 1: Hydraulic loss (A) and double pipe heat exchanger (B) LCDLM kits

The 2020 coronavirus pandemic has presented a unique challenge in our effort to disseminate and implement LCDLMs across the country; a majority of the participating universities in our study transitioned to an online teaching model in spring of 2020, making in-person use of the LCDLMs unfeasible. Over the past year, our team has developed several virtual implementation materials for the LCDLMs so that students may still experience the visual impact of the modules and complete the associated worksheet and conceptual and motivational assessments. In this paper we present a snapshot of virtual implementation materials as well as a subset of conceptual and motivational assessment results from virtual implementations over the past year. Additionally, we provide recommendations for the transition of simple classroom experiments to a virtual format based on our data.

Development of Virtual Materials

While developing the virtual LCDLM materials, we focused on several guiding principles:

- Clearly emphasize the visual aspects of the LCDLMs, such as pressure loss and flow patterns, as students respond positively to these aspects while using the modules
- Include quantitative measurements to allow students to complete theoretical calculations with data collected using the modules, as they would typically do
- Tailor materials for asynchronous courses by making them easily accessible via YouTube and provide in-depth conceptual instruction to supplement quantitative experimentation.
- Create flexible materials by limiting the length of videos and dividing materials for each module across several videos so instructors can choose what to assign.

With these principles in mind, we developed two types of videos for virtual LCDLM implementations: demonstration videos focused on experimentation with the modules and basic conceptual discussion about the experimental results, and short, animated videos focused on an in-depth, theoretical discussion of a single concept related to the LCDLM. The demonstration videos show data being collected in real-time, as students would do if they used modules in a traditional implementation, and students are encouraged to predict outcomes, record quantitative and qualitative data on a worksheet, and consider basic conceptual questions. The shorter concept videos provide theoretical explanations of conceptual aspects of the LCDLMs and introduce thought exercises designed to encourage students to utilize concepts from the video. Figure 2 shows a screenshot from the double pipe heat exchanger demonstration video and a screenshot from the venturi meter conceptual video focused on velocity trends.

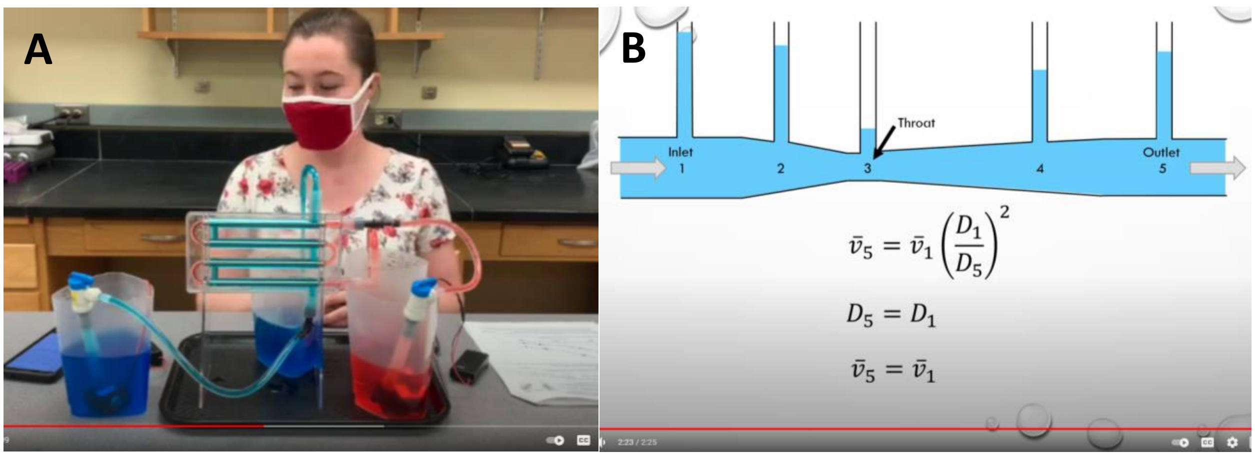

Figure 2: Screenshots from double pipe heat exchanger demonstration video (A) and venturi meter conceptual video (B)

In total, four demonstration videos and 13 conceptual videos are available for our hydraulic loss, venturi meter, double pipe heat exchanger, and shell and tube heat exchanger LCDLMs. All videos are publicly available on YouTube at https://www.youtube.com/channel/UCifbzlXEv-GazMBQkB-2uAA. The average length of the demonstration videos was 9:31 minutes, with the majority of the length used to show data collection for qualitative and quantitative data collection. In a typical hands-on classroom setting, students typically spend approximately 30 minutes performing experiments and completing conceptual discussions; thus, the experimental portion of virtual implementations was significantly shorter. The average length of the conceptual videos was 2:49 minutes and all videos had a length under 4:20 minutes.

Implementation Details and Use of Virtual Materials

From March 2020 to December 2020, twenty virtual implementations were completed at 11 institutions with approximately 390 second to fourth year chemical and mechanical engineering students. Table 1 shows statistics on which modules were used, whether the implementation was synchronous or asynchronous, and what portion of implementations allowed group work. From Table 1, it is clear that most instructors used the virtual LCDLM materials in an asynchronous setting as an individual activity, though a few instructors promoted a synchronous, interactive environment, incorporating peer discussion into the virtual activity. Only one asynchronous implementation allowed group work through peer discussion and four of the six synchronous implementations promoted group work, either through the use of Zoom breakout rooms or through discussion boards.

Table 1. Virtual Implementation Details

Module	**Number of Implementations**
Hydraulic Loss	6 (167 students)
Venturi Meter	2 (37 students)
Double Pipe HtX	8 (315 students)
Shell and Tube HtX	4 (83 students)
Class Format	
Synchronous	6
Asynchronous	14
Group Work	
Yes	5
No	15

To further characterize the use of the virtual materials, the views on the YouTube videos were tallied. Figure 3 shows the number of views for each of the four LCDLM demo videos. The views reported for the hydraulic loss, venturi, and double pipe heat exchanger conceptual videos represent the average number of views across all the conceptual videos available for the respective module. We note that the first conceptual videos published were for the double pipe heat exchanger and hydraulic loss module (April 2020). Conceptual videos for the venturi were added only recently in January 2021. The viewing data was tabulated on February 23, 2021.

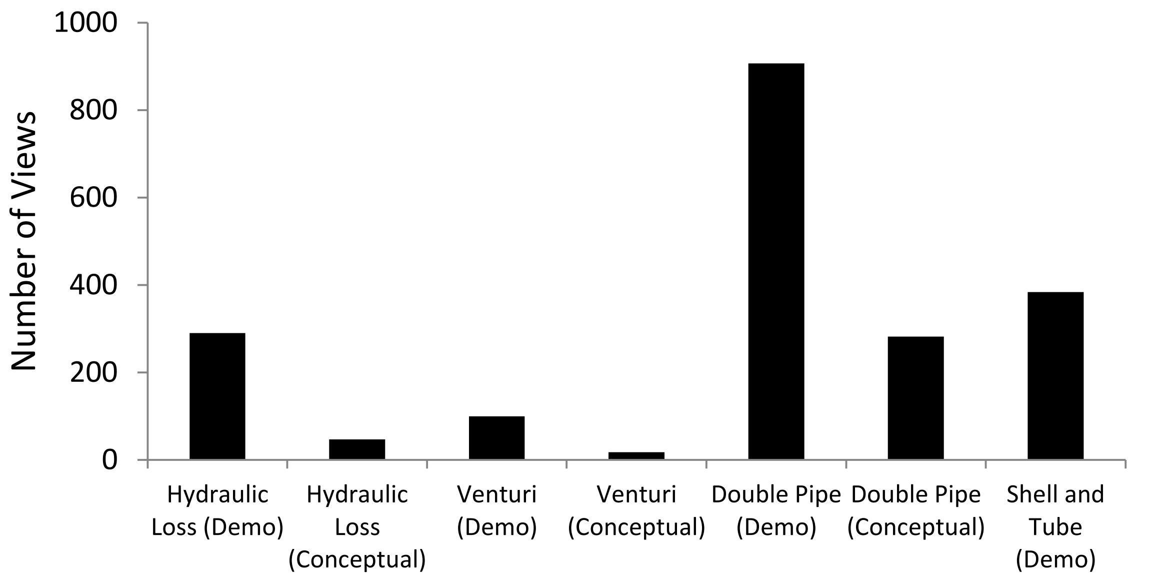

Figure 3. Number of views for LCDLM demonstration (demo) and conceptual videos

The conceptual videos, on average, were watched less frequently than the demonstration videos. Only four implementers reported that students were specifically asked to watch all the conceptual videos as well as the demonstration video, explaining this trend. Interesting to note is that the number of views for each of the demonstration videos is higher than the recorded number of student participants, particularly for the double pipe and shell and tube heat exchanger modules. This indicates that students may be watching videos multiple times or that the videos are being viewed by individuals not involved with the LCDLM project. The latter is likely, evidenced by the fact that 35% of viewer traffic occurred via YouTube searches, playlists, or suggested videos. Overall, the viewing data suggests that YouTube is an appropriate, easy-to-access platform which may promote extended reach of virtual materials beyond use by project participants. While our videos are tailored for use alongside the existing LCDLM worksheets, the highly visual nature of the LCDLMs and broad conceptual discussions in the demonstration videos may be useful to students not involved with the LCDLM project. Developers of virtual content should consider extended use potential when deciding whether to host virtual demo videos on similar platforms.

Conceptual Assessment Results

To determine whether virtual LCDLM implementations promote equivalent gains in conceptual understanding compared to traditional implementations, overall assessment results for spring 2020 virtual implementations and fall 2019 in-person implementations with the hydraulic loss module were compared and can be seen in Figure 4. The in-person data was averaged for 8 implementations at 5 universities (N=209), while the virtual data represents average results for 2 asynchronous implementations (one allowing discussion with peers) at 2 universities (N=73). Virtual implementation results for fall 2020 and spring 2021 and in-person results for other modules will be included in the final presentation after further analysis is complete.

Based on overall pre- and post-implementation conceptual scores, it is evident that both in-person and virtual implementations of the hydraulic loss are effective for increasing conceptual knowledge. Remarkably, similar average score increases, 26% and 21% were observed for in-person and virtual implementations, respectively. Also interesting to note is that, although students in in-person implementations demonstrated a lower level of existing knowledge evidenced by an 18% lower average pre-test score than student's completing the implementation virtually, both groups showed significant score increases. This indicates that both implementation formats are effective for increasing average conceptual understanding. In fact, some of the largest score improvements (40-50%) from the pre- to the posttest occurred for in-person implementations where students' pre-test scores were below 30%.

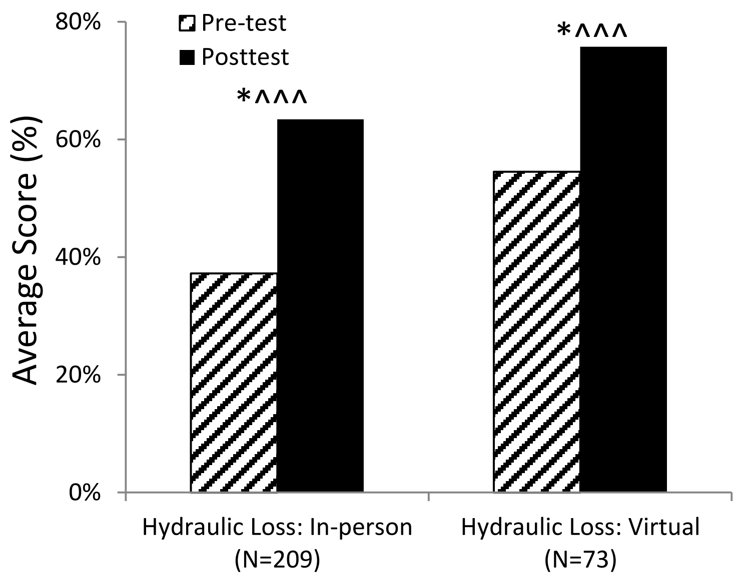

Figure 4. Pre- and post-implementation assessment results for in-person and virtual hydraulic loss implementations; * indicates statistically significant increase from pre- to posttest (p<0.01); ^^^ indicates large Cohen's d effect size (d>0.8).

When determining the effectiveness of active learning methods, it is also important to understand whether different activities promote improved understanding of similar concepts. A comparison of scores for in-person and virtual hydraulic loss implementations for three assessment questions are shown in Figure 5. Students were asked to (1) select the correct graph for velocity versus distance in a straight pipe connecting two tanks, (2) select the correct reasoning for their choice, and (3) select the correct method to reduce head loss in a straight pipe with options including changing the diameter, flow rate, or pipe roughness in these three multiple choice questions.

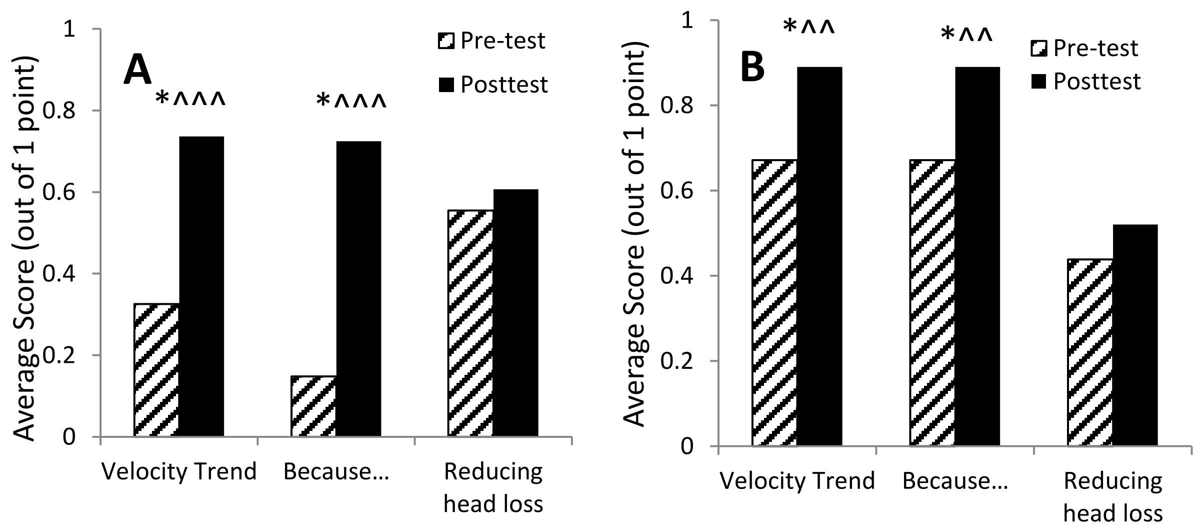

Figure 5. Hydraulic loss assessment question scores for 2019 in-person (A) and 2020 virtual (B) implementations; * indicates p<0.01; ^^ and ^^^ indicate medium and large effect sizes.

Results were comparable for both implementation formats. Students showed a significant score increase on questions related to correctly identifying the velocity trend in a constant diameter pipe and the reason for their choice in both implementation formats while there was not a significant understanding increase on strategies for reducing total head loss in a pipe with either format. However, it should be noted that for in-person implementations, students demonstrated lower prior knowledge on the pre-test and larger score increases for the velocity trend identification and reasoning question. The average score increase for the reasoning portion of the question showed the largest difference between groups, with a 0.57 point increase for the in-person students and a 0.22 point increase for the virtual students. Overall, these results show that in-person and virtual implementations not only promote the similar overall gains in conceptual understanding, but that they also meaningfully increase student understanding of similar individual concepts, although the magnitude of the changes in understanding may differ.

Engagement Assessment Results

To further compare student experience with in-person and virtual implementations, a series of Likert-scale questions related to engagement behaviors were asked following the LCDLM implementation. Behaviors were categorized by engagement mode: passive, active, constructive, or interactive, based on Chi's ICAP framework [3] and students were asked how the LCDLM allowed them to engage in each behavior compared to traditional lecture. Students were not told which engagement type behaviors were classified as which. Figure 6 shows the frequency that students self-reported engagement in interactive and passive behaviors for spring 2020 virtual and fall 2019 in-person implementations. Fewer virtual implementation students agreed or strongly agreed that the LCDLM activity helped them engage in interactive activities, for example, discussion with a peer, better than lecture. The total students agreeing the LCDLM activity promoted interactive behaviors was 50% in the virtual implementation group compared to 70% for the in-person group. This is not surprising, considering only a few virtual implementations allowed meaningful peer interaction while the majority of students completed an asynchronous, individual activity. However, students felt that both LCDLM activity formats prevented them from engaging in passive behaviors compared to lecture; 47% and 46% of in-person and virtual students, respectively, disagreed that they engaged in these behaviors.

A more thorough analysis of the engagement results will be included in the final presentation detailing any differences between the frequency of interactive and passive behaviors reported for asynchronous versus synchronous virtual implementations and for implementations with and without group work. We expect that students who engaged in synchronous implementations, especially those where group work was encouraged, will report a similar level of engagement in interactive behaviors compared to in-person students and higher engagement compared to students who completed the virtual activity individually in an asynchronous setting.

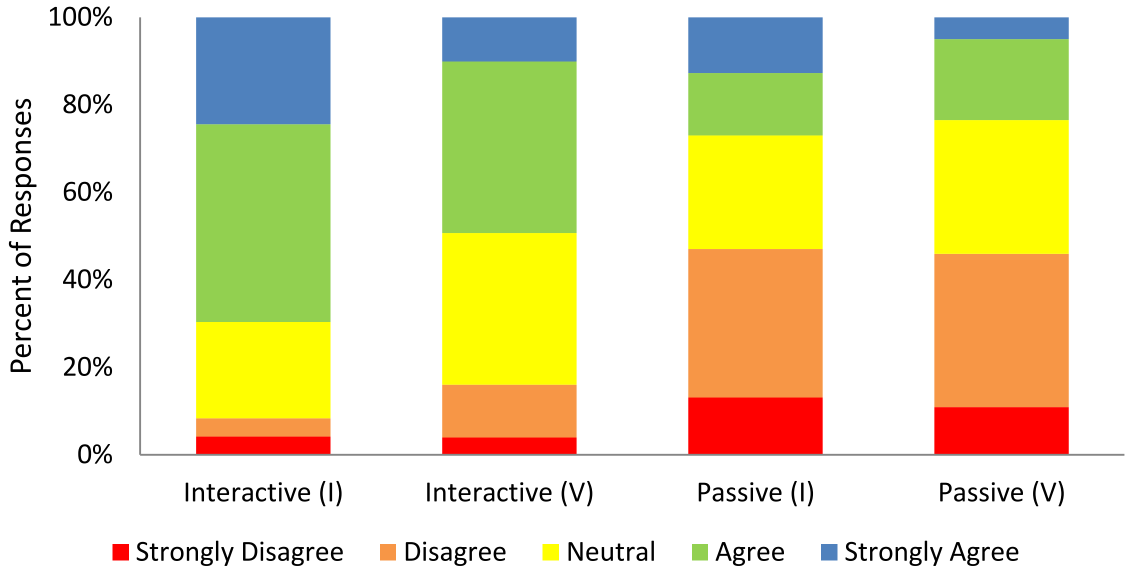

Figure 6. Likert-scale responses for engagement modes encouraged with LCDLM activities for in-person (I) and virtual (V) implementations.

In summary, initial results show that in-person students felt more interactively engaged than students who completed the virtual activity, though passive behaviors were prevented equally in both groups. Results for additional semesters and for active and constructive engagement behaviors during hand-on and virtual implementations will be shown in the final presentation.

Conclusions

The virtual materials developed by our team to transition our hands-on, interactive learning modules to a virtual format have been generally well-used and well-received. Based on conceptual and motivational results from spring 2020 virtual implementations, the flexible virtual activity promoted conceptual understanding gains and discouraged passive learning behaviors compared to traditional lecture. Initial comparison of virtual results to results obtained during in-person implementations show that both activity formats promoted similar learning gains and equivalent discouragement of passive behaviors; however, students who completed in-person implementations felt more interactively engaged than those who completed virtual implementations, highlighting the lack of valuable peer interaction in an asynchronous environment. The authors plan to conduct more detailed analysis including fall 2020 and spring 2021 data prior to the final conference presentation and provide evidence-based recommendations for best use of virtual, hands-on experimentation activities in an online course space. We believe the development of virtual laboratory activities can benefit traditionally online programs and resource-limited institutions, although in-person activities should still be employed where possible.

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