



## Financial Formulas and Lookup Functions (Combined PC/Mac): Circular References

Welcome to the next lesson. In this module on formulas and functions in Excel. We're going to cover a very specific topic here, which is circular references. And similar to the coverage of other topics like OFFSET, HLOOKUP, VLOOKUP and CHOOSE, we're not teaching this so much as a lesson in what to do but as a lesson in what to avoid and how to deal with circular references if you happen to see them in other peoples' models and work.

**Let's cover the basic idea of what a circular reference is first. Now before I do this demonstration, you should go to the options menu in Excel, Alt, T, O or  $\mathbb{C}$  + , on the Mac and go to formulas and make sure your workbook calculations are set to automatic except for data tables. Make sure Enable Iterative Calculation is checked. Set Max Iterations to 100 and set maximum change to 0.001. If you don't do this, this demonstration will not work correctly.**

[00:55]

This was the first lesson in the first module of this course, but your settings may have changed or you may not have actually looked at the first lesson. So, I'm repeating this now.

**With that, let's now enter a very simple example of a circular reference. So, in cell Q14, I will enter R14+Q14. We now see that there is a "Calculate" label at the very bottom left-hand corner of the spreadsheet. And this is because a circular reference is a case where the input of a cell depends on the output of that cell. So, here for example, we're saying that cell Q14 is equal to R14 plus Q14. So, Q14 is acting as both the input and the output of the cell. And when that happens, Excel gets somewhat confused about what is going on and has to use approximations to figure out what to do.**

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For example, here, if I entered 2 into cell R14 we get 200 here. How does that happen? It happens because, going back to our settings, we've told Excel that when we encounter a circular reference, we want it to iterate and go through 100 iterations or 100 loops to calculate the value. So, here, we take the zero, which is what Q14 is initially. We add 2 and we do that again and keep doing that 100 times until we get to 200 here.

Now we could play around with this and we can change it to other values and do other things like that. But you can see that Excel is always looping through this in some way, shape, or form to try to find the solution. So, the dependency could be direct, as it was in this example here,



where we literally take the cell and then input it into the formula in that cell, or it could be indirect.

For example, we could have something like this. Cell Q14=R14+S14. And then we could say here that cell S14 is equal to Q14+Q13. And now we also get a circular reference because of that "Calculate" label. Because so S13 depends on what's in cell Q14 but cell Q14 depends on what is an S14.

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**In real life, this tends to happen with interest income and cash balances for companies. A company will earn interest income based on its cash balance, but its cash balance will also change based on its interest income because if it earns more in interest, its cash balance will go up.**

As I said before, if you see "Calculate" in the bottom left-hand corner, it means you have a circular reference somewhere. If you get this and you don't know where exactly this circular reference is, one solution is to go to the options menu once again, formulas, and then disable the iterative calculations here. When you do this, Excel will then give you a visual and it will say at the bottom circular reference is cell Q14. And so it's very easy to tell what is feeding into what because of these arrows that Excel creates and the fact that it tells you the exact cell that has the circular reference at the bottom.

Now if there are multiple cells with circular references, you will only see one of them. But as you start fixing them, it will go away and you will be able to quickly find the problem in most cases.

[04:02]

So, that's a quick introduction to circular references. Let's now learn how to deal with them. And I'm going to do this demonstration by first showing you how people often list interest income and interest expense in financial models. I'll explain why that creates a circular reference by tracing through the inputs. And then I'll explain what we have to do or what we can do to fix it.

So, let's go over here and let's go down to the interest expense. So, at the interest expense on debt, we take the interest rate on debt that the company is going to pay, and then we multiply by the debt balance. There are a couple of debt balances here. We could take the beginning



debt balance, so the ending debt balance from the previous period, or we could take the ending debt balance from this period. Or we can take an average of both.

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**Now, if we just link it to the beginning debt balance, there are no problems because this old debt balance has nothing to do with the interest expense in the next year. But if we link it to the ending balance in this year or we try to do an average, then we run to that circular reference problem because now the ending debt balance will change based on the amount of interest expense paid in the year. That happens because if you look at how we're calculating the debt issued here, we're looking at the cash generated by the company and comparing that to its minimum cash balance. And if the company needs more cash, then it issues more debt.**

So, what people will often do here is take the average. And the argument for doing this is that it's more accurate if the company's debt balances increasing or decreasing over the course of the year to take the average balance and say that's the average amount the company pays interest expense on instead of just using the beginning or ending number.

So, we have this and we can see that we forgot to re-enable iterative calculations. So, we got this warning message. But let's go to options and check this again and now we can see this Calculate part at the bottom and we see what happens right here.

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So, we're using an average and that is why we get the circular reference. If you want to trace it line-by-line, it all goes back to the average of the debt balances here. So, here, for example, the ending debt balance that we're averaging is equal to the beginning debt balance plus debt issuances minus debt repayments.

**Now, debt repayments are fixed, so that doesn't create the circular reference. The debt issuances, though, depend on the company's minimum cash and the cash balance prior to debt issuances. And this cash balanced prior to debt issuances comes to us directly from the cash flow statement. So, the interest expense the company pays flows into net income and then that affects cash flow from operations, and then that affects the company's ending debt balance before any debt issuances. And so that's why we get the circular reference.**



We will get something similar when we do this for capital leases. So, here we have the interest in capital leases and then we take the average capital lease balance. I just use Alt, E, S, F to copy that down.

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And then for interest income, we can do something very similar. So, let's go up, we'll take the positive interest rate here and then we will go and average the cash balance. And again, this will create a circular reference for the same reason. The ending cash balance depends on the interest paid and earned during the year. And so the input of the cell is affected by the output of the cell. So, we have that.

And then at this point, people will often stop and then just copy this across and leave it like this and say, "Our model has circular references because we used average balances for cash, debt, and interest income, and interest expense." But the better way to deal with it is to build in some type of switch that lets you turn these off and on.

For example, in our model up here, we have average cash in debt balances for interest and this is our switch. Now, before you do this, again, you want to double check and make sure that you have checked Enable Iterative Calculations. But assuming you have, you would take note of this cell. You can see it has this name, Avg\_Balances, and then you could go down and you could do the following.

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Instead of just entering this formula as is, you could enter an IF statement here and you could say "IF(Avg\_Balances." You don't need to say equals one or equals true. Excel knows that if you just have that by itself, that's what you're really checking for. So, if we are averaging balances, then we'll do that. But if we're not, then we will just take the beginning debt balance right here and then we'll close that out.

Capital leases is pretty much the same thing. And then for interest income, it's also very similar: IF(Avg\_Balances, we will use the average. Otherwise, we will use the beginning cash balance right there and then we can copy this across. You can see the "Calculate" part now goes away because we don't have circular references anymore since we're linking to the beginning cash and debt balances.



If I change this to, yes, remember we're using data validation here to only allow 0 and 1 for no and yes, so if I change this and we go down, we can see that the numbers all change slightly and now we get this "Calculate" at the bottom indicating that we have a circular reference here.

[09:01]

For now, I'm going to change this back because we don't like to include circular references unless they're absolutely necessary. That's pretty much all we have to say on this topic. This is a relatively short lesson because I just wanted to cover the basics and explain how to deal with these.

To summarize, you should avoid circular references whenever possible. Sometimes you can't, but in a lot of cases, as with this interest example, you can easily do so. A circular reference is just a case where the input of a cell depends on the output of that cell. It could be a direct dependency as in a simple example here or it could be indirect as in the example in this model with interest income depending on the cash balance, but the cash balance depending on the interest income.

You know you have a circular reference if you see Calculate in the bottom left-hand corner. If you want to find and disable it, you can go to Options and uncheck Enable Iterative Calculations and Excel will trace through it and show you where the reference comes up.

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Normally, we prefer to deal with these by building an on/off switch and making sure that we have set it appropriately usually to off, but sometimes we'll turn it to on if we want to test it or look at other cases or something like that. In some cases, for example, sometimes in company valuations, if the company's share account depends on its implied share price, it's harder to get around circular references in that case, but even there, you could do some type of approximation if you want to disable circular references to allow that.

One of the disadvantages of circular references is that they make the model more unstable and harder to trace what's going on and harder to modify. So, that's why we usually prefer to leave them off. That's about it for this lesson. Coming up next, you'll learn how to audit formulas and use the trace dependents and precedents commands and select dependents and precedents commands to find problems and fix them.