Supporting Information

Clean synthesis of linear and star amphiphilic poly(ε-caprolactone)-*block*-poly(ethyl ethylene phosphonate) block copolymers: assessing self-assembly and surface activity

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Contents

1. Materials

ε-Caprolactone (ε-CL, 97%), *D*-sorbitol (>98%), anhydrous benzyl alcohol (BzOH, 99.8%), 1,6-hexanediol (HexD, 97%), tin (II) 2-ethylhexanoate ($Sn(Oct)_2$, 98%), 2-chloro-4,4,5,5-tetramethyl-1,3,2-dioxaphospholane (Cl-TMDP, 95%), 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU, 98%), were purchased from Sigma Aldrich (UK). 2-Ethyl-2-oxo-1,3,2-dioxaphospholane (EP) was synthesized according to literature.[1] Acetone (ACS grade) was obtained from VWR chemicals and all the solvents were of analytical grade or HPLC-grade and used as received. Supercritical Fluid Chromatography (SFC) grade carbon dioxide (minimum purity 99.9 %) was purchased from BOC gases (UK) and used as received. The commercial surfactants Tween™ 20 (PEG_{20}-sorbitan laurate, ~1230 g mol^{-1}), Tween™ 80 (PEG_{20}-sorbitan oleate, ~1310 g mol^{-1}) were supplied by Croda Europe Ltd. (UK). Pluronic™ L35 (PEG_{11}-PPG_{13}-PEG_{11}, 1900 Da) and Pluronic™ L64 (PEG_{13}-PPG_{30}-PEG_{13}, 2900 Da) were purchased from Sigma Aldrich (UK) and used as received. ε-CL was dried over CaH_2 for 48 h followed by vacuum distillation and stored under an inert atmosphere. 1,6-Hexanediol, *D*-sorbitol and $Sn(Oct)_2$ were stored in a desiccator and dried under vacuum at 25 °C overnight before use. Ultrapure water with a resistivity of 18.2 MΩ cm^{-1} was obtained from the Milli-Q system (Merck Millipore®). Regenerated cellulose dialysis membranes with a molecular weight cut-off (MWCO) of 1000 g/mol, Spectra/Por® 7, were purchased from Carl Roth.

2. Monomer synthesis

Ethyl phosphonate (EP) monomer was synthesised according to the two-step literature procedure.[1]

Synthesis of Ethyl Phosphonic Dichloride. Briefly, a mixture of O, O-diethyl ethyl phosphonate (252.8 g, 1.52 mol) and DMF (1.26 mL) was added dropwise to refluxing thionyl chloride (275.9 mL, 3.80 mol) at 75 °C. Strong gas evolution of methylene chloride and sulfur dioxide indicated the progress of the reaction. After 24 h the gas evolution declined. The reaction mixture was stirred under reflux for additional 66 h to complete the chlorination. Fractionated distillation of the raw product yielded the desired ethyl phosphonic dichloride as a colourless liquid (202.0 g, yield 99.9%, b.p 40-42°C /7 × 10^{-2} mbar). ^{1}H NMR (300 MHz, CDCl$_3$) δ (ppm) 2.53 (dq, ^{2}J HP = 15 Hz, ^{3}J HH = 7.5 Hz, 2H), 1.32 (dt, ^{3}J HP = 30 Hz, ^{3}J HP = 7.5 Hz, 3H). ^{31}P{H} NMR (121 MHz, CDCl$_3$) δ = 54.72.

Synthesis of 2-ethyl-2-oxo-1,3,2-dioxaphospholane. A flame-dried three-necked round bottom flask of 2000 mL equipped with a magnetic stirring bar and two dropping funnels was charged with 400 mL of dry THF under an inert atmosphere and cooled to −21 °C in an ice-bath. Ethyl phosphonic dichloride (153.4 g, 1.04 mol) was dissolved in dry THF (400 mL) and transferred into one dropping funnel via a flame-dried stainless steel capillary. A solution of dry ethylene glycol (64.8 g, 1.04 mol) and dry pyridine (165.1 g, 2.08 mol) in THF (168.5 mL) was transferred into the second dropping funnel via a flame-dried stainless steel capillary. Dropping speed was adjusted to be approximately equal for both mixtures. After complete addition, the solution was stirred for 6 hours and stored overnight at −28 °C to facilitate the precipitation of the pyridinium hydrochloride by-product. The precipitate was removed by filtration via a flame-dried Schlenk funnel and the solvent was removed at reduced pressure (10^{-1} - 10^{-2} mbar). First fractionated distillation yielded the product as a yellow liquid (92.6 g, yield: 70 %, b.p. 67.°C/ 1 × 10^{-2} mbar). Second fractionated distillation yielded the desired product as a colourless liquid (86.3 g, yield 61 %, b.p. 61 °C/ 2.1 × 10^{-3} mbar). The monomer was stored under an inert atmosphere at -20 °C.

3. Purification Methods

By Supercritical CO_2 Fluid Extraction (SCFE). As a general procedure, typically 2.00 - 2.5 g of crude polymer product was introduced to a 20 mL autoclave followed by mechanical agitation (at 100 rpm for 25 min) to establish a dissolving equilibrium. Extractions were typically conducted at 38 ± 2 °C and 140 ± 5 bar (ρ of 766 kg m^{-3}) at a constant flow rate under mechanical stirring at 200 rpm. The extraction efficiency of each sample was monitored by taking an aliquot from the base of the autoclave after every 10 min (and the extracted fraction was analyzed simultaneously after each step).

By Dialysis using a Semi-Permeable Membrane. The crude product (0.25 – 1.0 g) was dissolved in a mixture of acetone and water (typically 0.5:6 mL v/v) and dialyzed against water (200 – 250 mL) for 6 h. Followed by lyophilization to obtain a dry product.

4. Instrumentation and Characterization Method

Nuclear Magnetic Resonance Spectroscopy (NMR). NMR spectra were typically recorded on a Bruker Avance spectrometer operating at 300 MHz or 400 MHz with chemical shifts in parts per million (ppm) referenced relative to the deuterated solvent; DMSO-d_6, or CDCl$_3$. ^{1}H NMR was performed to evaluate conversions of the performed polymerizations (% conv.) and analyses the number average molecular weights (M_n) of the synthesized polymers.

Size Exclusion Chromatography-Multi Angle Light Scattering (SEC-MALS). SEC-MALS measurements were performed on Agilent 1260 Infinity triple detection SEC set-up comprising a Wyatt Optilab MALS detector, and an Agilent differential refractometer. Separation was achieved using 2 PLgel mixed D columns (7.5 mm × 50 mm). The eluent was tetrahydrofuran (THF) at room temperature at a flow rate of 1 mL/min. The refractive index increment (dn/dc) of star D-sorbitol-PCL was determined using a representative sample, star D-sorbitol[PCL$_{9.7}$OH]$_{5.1}$. (Refer to Baheti et al.[2]) Five different concentrations of star D-sorbitol[PCL$_{9.7}$OH]$_{5.1}$ in THF were injected and the resulting RI signals were plotted as a function of concentration. The dn/dc value of 0.074 ± 0.04 mL/g was obtained as the gradient of a linear fit using the ASTRA software, which is in good agreement with the dn/dc value from the literature for linear PCL in THF at 25 °C (dn/dc = 0.072 mL/g).[3] Therefore, this value (dn/dc = 0.072 mL/g) was used for the MALS analysis of all samples in this work.

Conventional Size Exclusion Chromatography (SEC). For the molecular weight analysis by conventional column calibration of water-soluble and amphiphilic polymers, three different SEC methods were employed.

SEC (Refractive Index, PMMA) (SEC (RI, PMMA standard)). SEC (RI, PMMA standard) was carried out using a PL50 Polymer Laboratories system equipped with a refractive index detector, employing 2 mixed D columns at 50 °C, using dimethylformamide + 0.1 wt% LiCl as the mobile phase at a flow rate of 1 mL/min. Poly(methyl methacrylate) (PMMA) standards (M_n range: 505 to 1,810,000 g/mol) were used to calibrate the SEC.

SEC (Refractive Index, PEG) (SEC (RI, PEG)). SEC (RI, PEG standard) measurements were performed in DMF (containing 0.25 g/L of LiBr as an additive) at 50 °C and a flow rate of 1 mL/min with an Agilent 1100 Series integrated instrument, including a PSS HEMA

column (M_n range: $10^6/10^5/10^4$ g/mol) and a refractive index detector. Calibration was carried out using poly(ethylene glycol) (PEG) standards provided by Polymer Standards Service.

SEC (Refractive Index, Double Angle Light Scattering) (SEC (RI, Double Angle LS). SEC (RI, Double Angle LS) measurements were conducted on a system composed of a Varian 390-LC Multidetector suite fitted with a differential refractive index, double angle light scattering, and viscosimeter detector equipped with a guard column (Agilent PolarGel L 8 μM, 50 × 7.5 mm) and two PolarGel L columns (Agilent 5μM, 300 × 7.5 mm). The mobile phase was dimethylformamide (DMF) with 0.1wt% LiCl at 40 °C, at a flow rate of 0.8 mL/min. The results were calibrated against poly(methyl methacrylate) (PMMA) standards (M_n range: 1010 – 68000 g/mol) using Cirrus v3.3 software.

Matrix Assisted Laser Desorption and Ionization-Time of Flight Mass Spectrometry (MALDI-TOF MS). MALDI-TOF MS were recorded on a Bruker RapiFlex spectrometer operating at the following conditions: Nitrogen laser (337 nm), accelerating potential (20 kV) in positive linear ion or reflection mode. In delayed extraction mode, the delay time was ∼300 ns optimized based on the mass range of the polymer distributions. External calibration was performed using PEG polymer standards. Trans-2-[3-(4-*tert*-butylphenyl)-2-methyl-2-propenylidene]malononitrile (DCTB) was employed as the matrix. An analyte solution and matrix solution with a concentration of 10 g/L in THF (1:4 v/v analyte-to-matrix solution) were mixed with 1 μL of potassium trifluoroacetate (10 g/L). An analyte solution (at 40 g/L in THF) and matrix solution with a concentration of 10 g/L in THF (1:4 v/v analyte-to-matrix solution) were mixed with 1 μL of potassium trifluoroacetate (10 g/L) (K^+ ionization). 1 μL of the resulting mixture was spotted on the MALDI plate for MS analysis. Data were analyzed and normalized using the FlexAnalysis version 3.0 (Bruker) software.

Dynamic Light Scattering (DLS). DLS measurements were performed on a Malvern Zetasizer Nano-ZS to determine the hydrodynamic diameter of the polymeric particles in water. The samples were placed in a polystyrene disposable cuvettes and analyses were performed at 25 °C on a 1 mL sample in Milli Q water as a solvent collecting the scattered light at a detection angle of 173° using the CONTIN method for analysis. Data analysis was performed using the Zetasizer software version 7.12 and mean values obtained from three independent

measurements were reported. The hydrodynamic diameter (D_H) was calculated from the Stokes-Einstein relation as follows: $D_H = \dfrac{k_B T}{3\pi\eta D}$

where k_B is the Boltzmann constant, T is the temperature, and η is the viscosity of the medium (0.087 cP), and D is the apparent diffusion coefficient.[1]

(i) Direct suspension method. The copolymers were directly dissolved in Milli-Q water at a concentration of 1 mg mL^{-1} (0.1 wt%) and 5 mg mL^{-1} (0.5 wt%) magnetically stirred at 500 rpm overnight at ambient temperature and allowed to equilibrate in a disposable cuvette for 1 h, at ambient temperature prior to analysis.

(ii) Nanoprecipitation. Nanoprecipitation method was adapted from Kakde *et al.*[2] The self-assembled nanoparticles of the star diblock copolymers were prepared by dissolving the copolymers (20 mg) in acetone (10 mL) and adding this solution into Milli- Q water (20 mL) with a syringe pump operating at a fixed rate of 0.5 mL/min while stirring (1000 rpm). The final solvent to anti-solvent (acetone to water) composition was fixed at a 1:2 v/v ratio. The suspension was stirred for 4 h at ambient temperature and acetone was evaporated under vacuum. The suspensions at 1 mg/mL concentration were slowly transferred to a polystyrene disposable cuvette prior to analysis.

Transmission Electron Microscopy (TEM). TEM micrographs were obtained using a Tecnai G2 (FEI, Oregon, USA) microscope and discussed.

The star D-sorbitol[PCL$_{57}$-b-PEP$_{36}$OH$_6$] copolymer suspension in Milli-Q water (1 mg mL^{-1}) obtained by the nanoprecipitation method was diluted 10- fold and one drop (~3 μL), was cast on a flip side of a graphene oxide coated holey carbon copper grid (EM Resolutions, UK) (held upside down), and suspended in air for 90 sec. For drying of the water, a gentle flow of argon was passed on the grid. Samples were then imaged at 100 kV using TIA imaging software, without staining, at a magnification of × 43 000 up to 300 000.

Cryogenic Transmission Electron Microscopy (Cryo-TEM). Cryo-TEM samples were prepared employing a custom-built chamber (often) referred as the controlled environment vitrification system (CEVS). About 3.5 μL of the star D-sorbitol[PCL$_{57}$-b-PEP$_{36}$OH$_6$] copolymer in Milli-Q water (1 mg/mL) was placed onto the glow-discharged holey carbon-coated copper grid for about 3 min. Excess of water was soaked by a filter paper in CEVS after a minimum of 30-sec detainment; the sample grid was flash-frozen (vitrified) by plunging it

into liquid ethane. The grid with the vitrified sample solution had been maintained at liquid nitrogen temperature before the analysis was performed. Cryo TEM was performed on a JEOL JEM-2100 Plus electron microscope instrument with an acceleration voltage of 200 kV at a magnification of × 200 000.

Krüss Tensiometer. The surface tension measurements were performed at 0.5 wt% concentration (typically 60 mL) in ultrapure water with a resistivity of 18.2 MΩ/cm (Milli-Q, Millipore®) at ambient temperature (25 ± 0.5 °C) and at natural pH on a Force Tensiometer (Krüss K100). The Wilhelmy platinum plate was flame cleaned on a Bunsen burner after each new series of measurement. Between runs, the glass vessel was cleaned with isopropyl alcohol (or ethanol) followed by rinsing several times with Milli-Q water. In all cases, 50 successive measurements were repeated until a standard deviation of ≤0.03 mN/m (for static) or ≤ 0.0001 mN/m (for equilibrium) was obtained. For precise measurements, tensiometer was calibrated by measuring the surface tension of Milli- Q water before every reading.

Critical Aggregation Concentration (CAC). For PCL_n-b-PEP_m based block copolymers the CAC was determined by Wilhelmy plate method using a fully automated micro dispenser equipment on K100 (Croda), which enabled a high number of measuring points at a broad concentration range (0.1-10000 mg/L). Typically, a starting concentration of 0.5 wt% was prepared and the aqueous solution was diluted stepwise, measuring the surface tension at each point. This high number of measurements increases the accuracy of the CAC determination. Surface tension vs. concentration (in μM, log scale) was plotted and the CAC value was calculated at the intersection between the descending line and close to the horizontal line (as the surface tension will plateau above the CAC) (applied on amphiphilic samples).

5. Analytical characterization of polymers

Table S1. Analytical data and thermal characteristics for linear PCL_n-b-PEP_m diblock and linear $PEP_{m/2}$-b-PCL_n-b-$PEP_{m/2}$ triblock copolymers synthesized in the bulk.

Entry	Code [a]	$[M]_0:[I]_0:[C]_0$	Conv [d] (%)	t (h)	DP_n [d]	M_n^{NMR} [e] (g/mol) (macro-initiator)	M_n^{NMR} [e] (g/mol) (PEP block)	M_n^{Copol} [f] (g/mol)	$M_n^{SEC-DMF}$ (g/mol)	$Đ$ [g]
1	HO-PCL$_4$-OH	4.2:1:0.1 [b]	99	0.5	4.0	600	-	-	600 [g]	1.25
2	PEP$_{1.6}$-b-PCL$_4$-b-PEP$_{1.6}$	5.3:1:0.5 [c]	88	2	3.2	-	440	1040	850 [g]	1.29
3	PEP$_{3.6}$-b-PCL$_4$-b-PEP$_{3.6}$	9.6:1:0.5 [c]	94	2	7.3	-	1000	1600	1100 [g]	1.34

[a] Sample label, the subscripts represent the degree of polymerization of PCL and PEP blocks determined from ^{1}H NMR. [b,c] Molar ratio of $[Monomer]_0:[Initiator]_0:[Catalyst]_0$ based on $DP_n^{targ} = [M]/[I]$ for macroinitiators:
[b] $[\varepsilon\text{-CL}]_0:[HexD]_0:[Sn(Oct)_2]_0$, [c] $[EP]_0:[macroinitiator]_0:[DBU]_0$.
[d] Determined by ^{1}H NMR after purification (after SCFE).
[e] M_n^{NMR} (macroinitiator) and M_n^{NMR} (PEP block) determined by ^{1}H NMR following eq. S1 and S3 respectively.
[f] M_n^{Copoly} is M_n^{NMR} (macroinitiator) + M_n^{NMR} (PEP block) (eq. S4)
[g] Determined *via* SEC (RI, PEG standards) in DMF at 50 °C.

Table S2. Equations

PCL macroinitiator	M_n^{NMR} (macroinitiator) $= (DP^{NMR} \times M_{\varepsilon\text{-CL}}) + M_I$	eq. S1
PEP block	DP^{NMR} (PEP block) $= \left(\dfrac{(\int 4.13)/4}{(\int 3.99)/2} \right) \times DP^{NMR}$ (PCL block)	eq. S2
	M_n^{NMR} (PEP block) $= (DP^{NMR}$ (PEP block) $\times M_{EP})$	eq. S3
Copolymer	$M_n^{Copoly} = M_n^{NMR}$ (PEP block) $+ M_n^{NMR}$ (macroinitiator)	eq. S4

Where $M_{n\ macroinitiator}^{NMR}$ corresponds to the molar mass of whole PCL macroinitiator chain. $M_{\varepsilon\text{-CL}}$ to the molar mass of ε-CL (114.14 g/mol) and M_{EP} to ethyl ethylene phosphonate (136.02 g/mol), M_I to the benzyl alcohol (108.14 g/mol) for monohydroxy Bz-PCL$_{19}$OH and to 1,6-hexanediol (118.18 g/mol) for dihydroxy HO-PCL$_n$-OH macroinitiators, respectively.
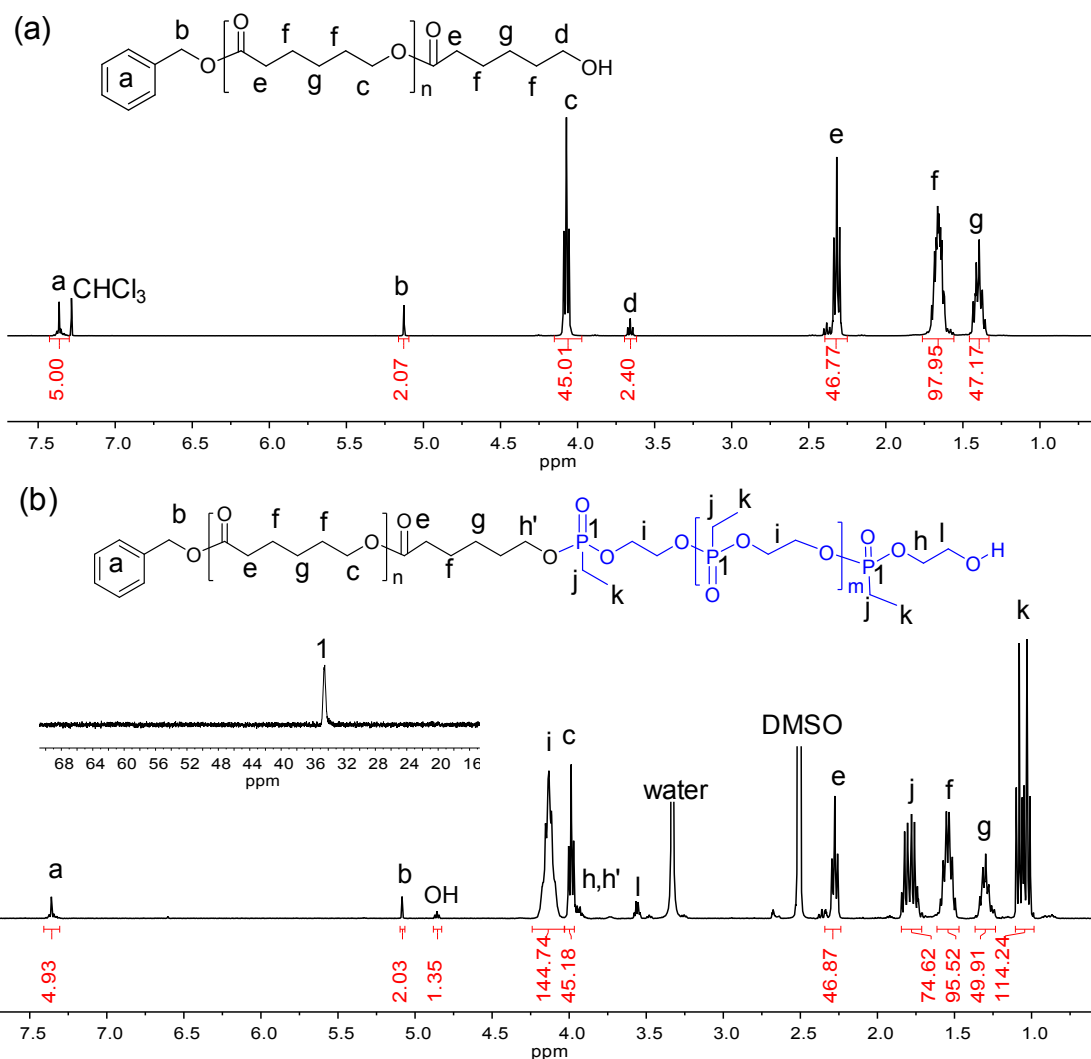
Figure S1. ^{1}H NMR spectra of purified polymers (a) linear Bz-PCL$_{19}$OH homopolymer (solvent CDCl$_3$) to aid the interpretation for the diblock and (b) linear Bz-PCL$_{19}$-*b*-PEP$_{30}$ diblock copolymer (solvent DMSO-*d*$_6$) synthesized in the bulk. The resonance of the methylene protons adjacent to the hydroxy end-group of linear Bz-PCL$_{19}$OH (δ 3.66 ppm –CH$_2$C*H*$_2$OH, **d**) vanishes in the Bz-PCL$_{19}$-*b*-PEP$_{30}$ copolymer and a new multiplet appears (δ 3.56 ppm) corresponding to the hydroxymethyl of the phosphoester backbone (–OP(=O)–O–CH$_2$–C*H*$_2$–OH, **i**) ((Figure S1, (a) vs (b), Figure 1 (b)). The inset shows the corresponding ^{31}P NMR spectrum. Note the different solvent employed for NMR analysis is due to the solubility difference between homopolymer (solvent CDCl$_3$) and copolymer (solvent DMSO-*d*$_6$).

In the ^{1}H NMR (CDCl$_3$) spectrum of Bz-PCL$_{19}$OH, multiplets at δ 1.54 and 1.29 ppm were assigned to the methylene protons (–C(=O)CH$_2$C*H*$_2$C*H*$_2$CH$_2$CH$_2$O–, **f** and **g**) of the ε-CL units. The signal associated to the methylene ester protons of the carboxy group (–C*H*$_2$OC(=O)–, **c**) and methylene protons of the carbonyl group (–OC(=O)C*H*$_2$CH$_2$–, **e**) were visible at δ 3.98 and δ 2.27 ppm respectively. The resonance δ 7.42 – 7.30 ppm was assigned to aromatic benzylic protons (C$_6$H$_5$–, **a**) and at δ 5.08 ppm to aryl protons (C$_6$H$_5$C*H*$_2$–, **b**) (Figure S1 (a)).

Specifically, the signal at δ 3.66 ppm is due to the methylene protons ($-CH_2CH_2OH$, **d**) in α-position to the hydroxy end-groups of linear Bz-PCL$_{19}$OH. It is noteworthy that in ^{1}H NMR (DMSO-d_6) spectrum of Bz-PCL$_{19}$-b-PEP$_{30}$ copolymer, this methylene proton signal disappears. A new multiplet appears at δ 3.56 ppm corresponding to the methylene protons in α-position to the hydroxy group of the phosphoester backbone ($-OP(=O)-O-CH_2-CH_2-OH$, **i**) (Figure S1 (b)). This indicates that all the terminal hydroxy signals of PCL chains have initiated the AROP of the EP monomer. The signal associated to the methylene protons of PEP backbone ($-O-CH_2-CH_2-O-$, **i**) in the Bz-PCL$_{19}$-b-PEP$_{30}$ diblock copolymer were visible at δ 4.43 − 4.22 ppm and methylene protons of the pendant ethyl group ($-OP(=O)-(CH_2CH_3)-$, **j**) at δ 1.84 − 1.64 ppm whereas the methyl groups ($-OP(=O)-(CH_2CH_3)-$, **k**) resonate between δ 1.14 − 0.97 ppm. The signal at δ 3.89 ppm were assigned to the methylene in β-position to a hydroxy group ($-OP(=O)-O-CH_2-CH_2-OH$, **h**). Thus, ^{1}H NMR spectroscopy confirmed the successful growth of the PEP block from the Bz-PCL$_{19}$OH macroinitiator.

The degree of polymerization (DP^{NMR}) for Bz-PCL$_{19}$OH was determined by comparing the resonances originating from ε-CL repeating unit (**e**, 2.27 ppm) with the end-group hydroxymethyl protons (**d**, 3.66 ppm) to give DP^{NMR} of 19 (~19.5) (Figure S1 (b)) and M_n^{NMR} (macroinitiator)) 2300 g/mol (eq. S1, Table S2). The monomer conversions after chain extension were calculated using the resonance unreacted monomer: EP at δ 4.50−4.24 ppm (4H, $-P-O-CH_2CH_2-$) compared with the corresponding EP repeating units (**i**) in the copolymer at δ 4.43 − 4.22 ppm. The DP^{NMR} value of the PEP block in the Bz-PCL$_{19}$-b-PEP$_{30}$ was determined from the phosphonate backbone protons (δ 4.14 ppm, **i**) with those of the methylene protons in PCL (δ 3.99 ppm, **c**). Thus, DP^{NMR} of 30 (~29.8) and M_n^{NMR} (PEP block) value of 4100 g/mol were observed (eq. S2 and eq. S3, Table S2). Thus, total molecular weight of the diblock copolymer (M_n^{Copoly}) could be estimated at 6400 g/mol (eq. S4, Table S2).

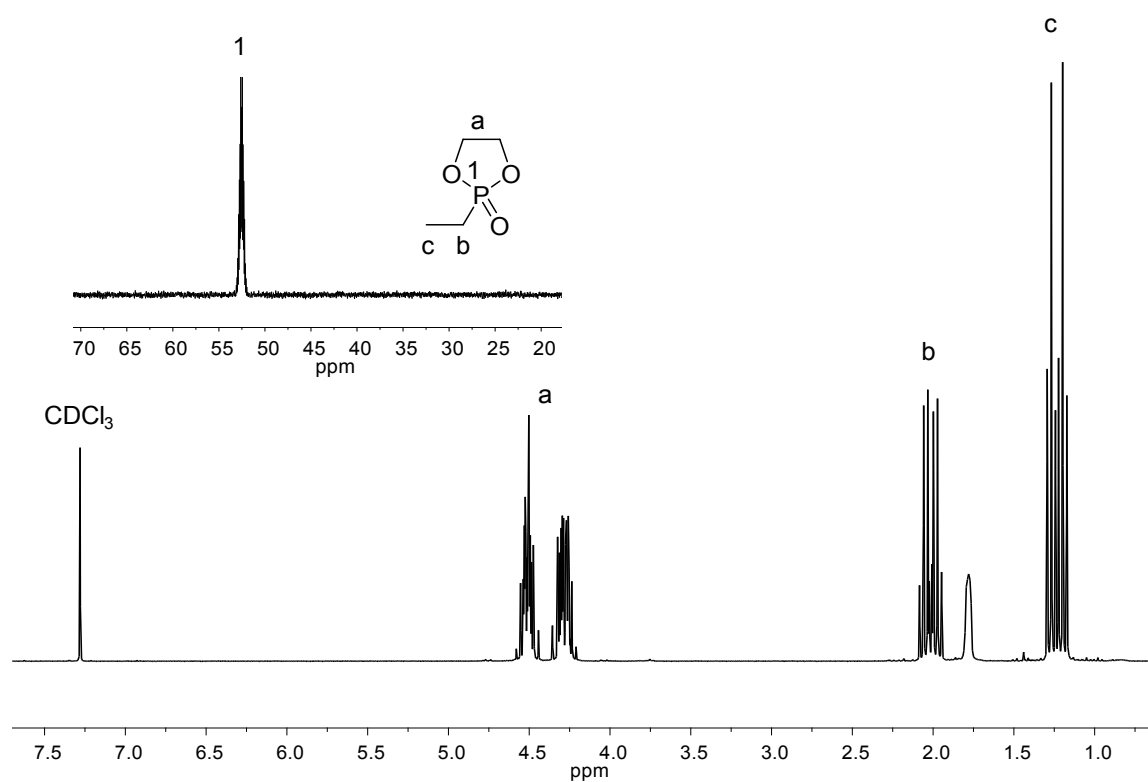The ^{1}H and ^{31}P NMR spectra of EP monomer are presented (Figure S2).

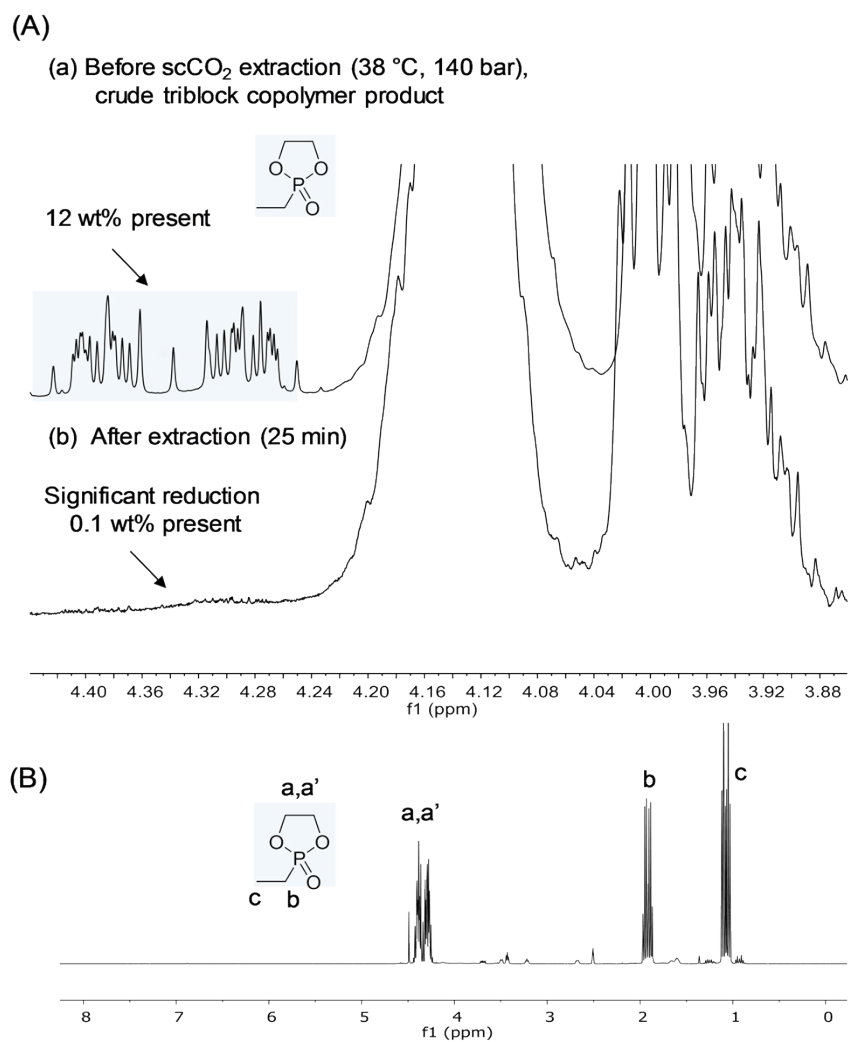**Figure S2.** ^{1}H NMR spectrum of the EP monomer and ^{31}P NMR inset (solvent CDCl$_3$).

Figure S3 (A). ^{1}H NMR spectra of the PEP$_{3.6}$-*b*-PCL$_4$-*b*-PEP$_{3.6}$ triblock copolymer synthesized in the bulk at 60 °C (a) crude triblock product before and (b) after extraction for 25 min showing a significant (~11.5 wt%, ~300 mg) reduction in the intensity of ethyl phosphonate signals when extracting using scCO$_2$ (38 °C, 140 bar) and (B) ^{1}H NMR of extracted material.
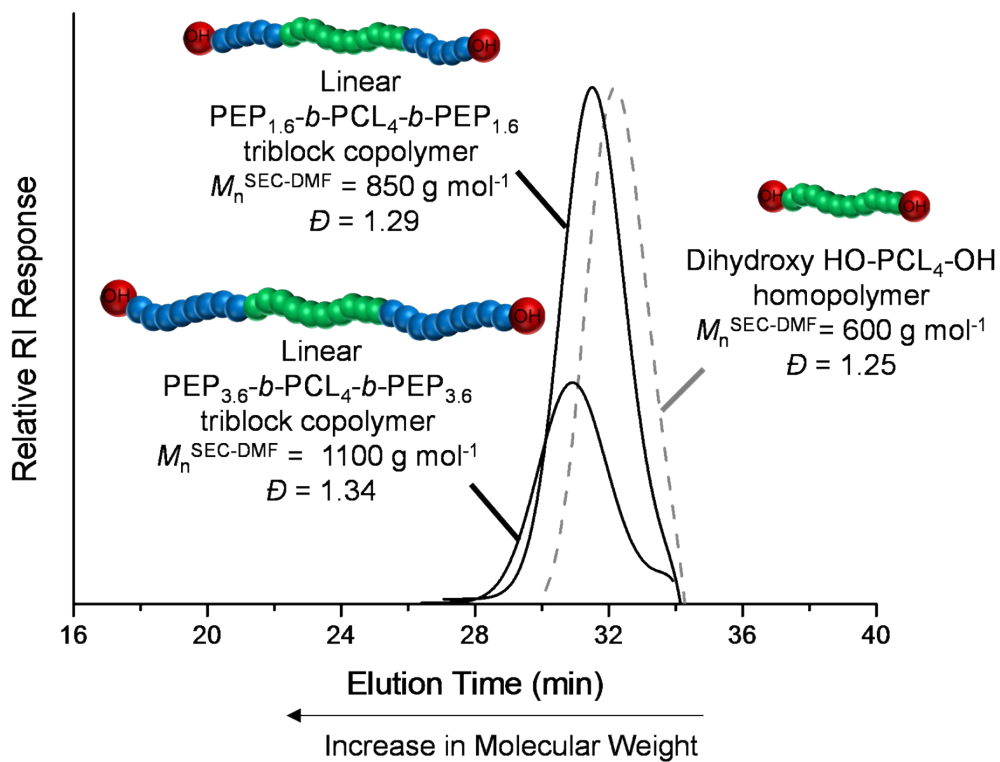
Figure S4. SEC (RI, PEG standard) traces of dihydroxy OH-PCL$_4$-OH and the corresponding triblock PEP$_m$-b-PCL$_n$-b-PEP$_m$ copolymers.
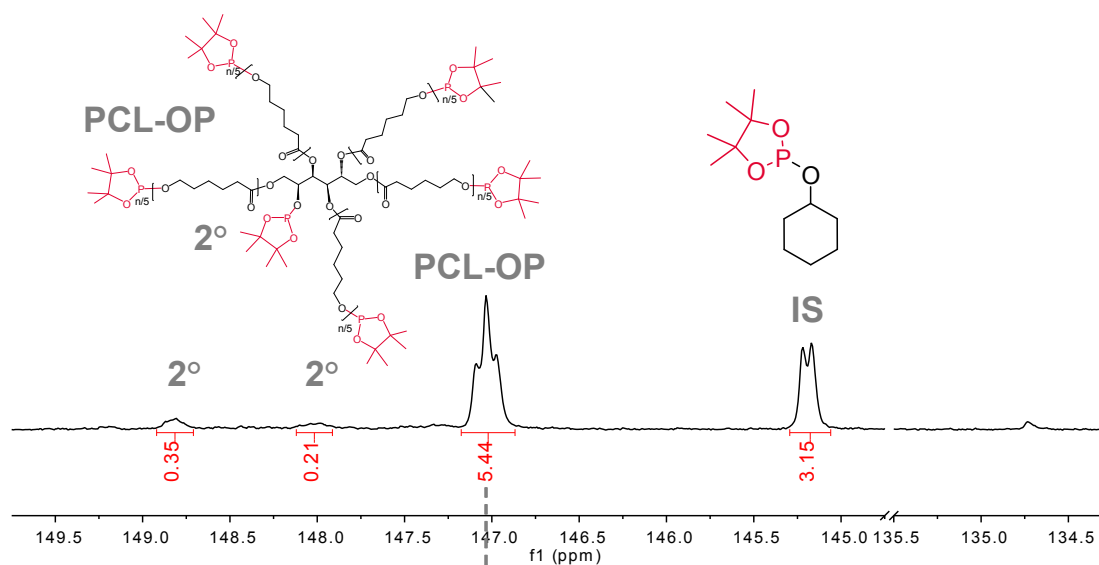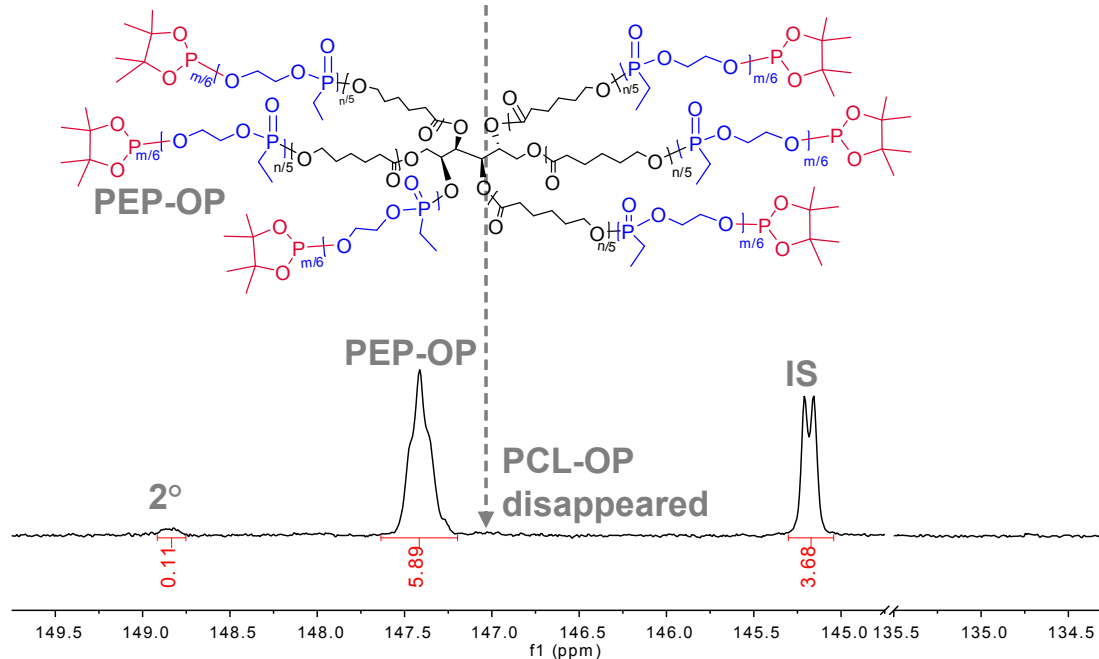
Figure S5. ^{31}P NMR spectra without decoupling of phosphitylated (a) star *D*-sorbitol[PCL$_{57}$OH$_5$]OH showing residual secondary hydroxy groups on the *D*-sorbitol core and (b) star *D*-sorbitol[PCL$_{57}$-*b*-PEP$_{36}$OH$_6$] diblock copolymers showing barely any signal from secondary hydroxy groups on *D*-sorbitol and full disappearance of signals originating from the PCL-OH. IS: internal standard (cyclohexanol). The integrals are normalized.

Table S3. Hydrophilic-lipophilic balance of amphiphilic linear and star PCL_n-b-PEP_m diblock and linear PEP_m-b-PCL_n-b-PEP_m triblock copolymer.

Entry	Code[a]		Amphiphilic copolymers	Hydrophilicity[b]
1	Int. MW linear diblock	Linear diblock	Linear diblock Bz-PCL_{19}-b-PEP_{30}	12.8
2	Low MW linear triblock	Triblock 1	Triblock $PEP_{1.6}$-b-PCL_4-b-$PEP_{1.6}$	8.5
3		Triblock 2	Triblock $PEP_{3.6}$-b-PCL_4-b-$PEP_{3.6}$	12.5
4		Triblock 3	Triblock $PEP_{7.2}$-b-PCL_9-b-$PEP_{7.2}$	12.9
5	Int. MW star diblock	Int. MW Star	star D-sorbitol[PCL_{18}-b-$PEP_{27}OH_6$]	12.3
6	High MW star diblock	High MW Star	star D-sorbitol[PCL_{57}-b-$PEP_{36}OH_6$]	8.4

[a] Abbreviation, amphiphilic copolymers.

[b] Calculated, hydrophilicity $= 20 \times [M_n^{NMR}$ (PEP block)$/M_n^{Copoly}]$, adapting Griffin's formula of HLB on scale of 0 to 20 where 0 is fully lipophilic and 20 is fully hydrophilic. Da = Dalton.
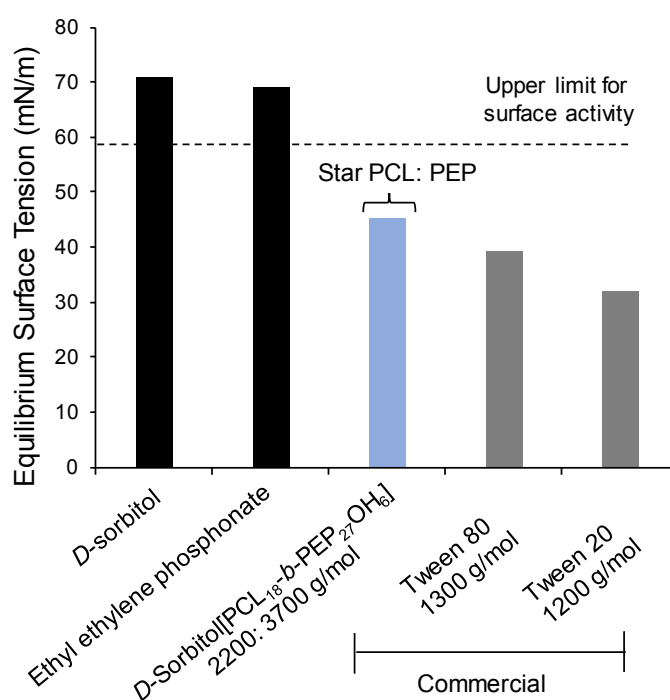

Figure S6. Equilibrium surface tension values of the D-sorbitol and ethyl phosphonate building blocks (black bars) and synthesized star D-sorbitol[PCL_n-b-PEP_m] diblock copolymer (blue bars) measured against some commercial standard surfactants (grey bars). Compounds below the dashed line are considered surface-active agents.
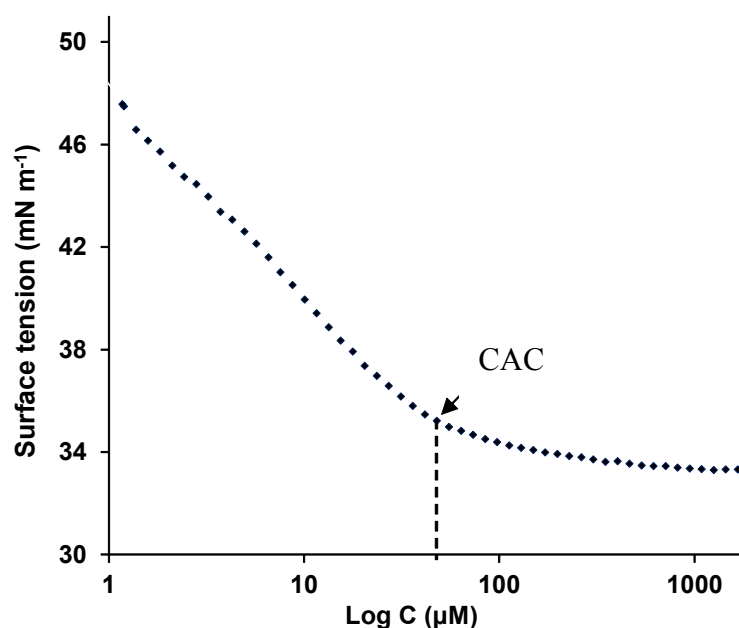
Figure S7. Surface tension (γ) plotted *vs.* log C (linear triblock PEP$_{7.2}$-*b*-PCL$_9$-*b*-PEP$_{7.2}$). Determination of CAC of the linear PEP$_{7.2}$-*b*-PCL$_9$-*b*-PEP$_{7.2}$ triblock copolymer (1000:1100:1000 g/mol) (Triblock 3) following the Wilhelmy plate method. The CAC value calculated at the intersection between the two linear portions of the curve is 47.9 μM (0.014 wt%).

For conventional linear surfactants, the surface tension decreases with an increase in amphiphile concentration up to a certain point (CAC) and then becomes nearly constant. Only when the interface becomes saturated does further addition of surfactant lead to aggregation/micellization. Typically, star amphiphile displayed similar trend in lowering the surface tension gradually with increasing its concentration in water up to 0.012 wt% concentration ($\gamma = 49$ mN/m) (Figure S8). Surprisingly, the surface tension kept reducing until 46.9 mN/m (at 0.5 wt%) (Figure S7 vs. Figure S8). Overall two regimes were observed, and by extrapolating the graph at the intersection between two regimes, a critical point might estimate to be 21.2 μM (0.012 wt%). Though, this critical point cannot be unambiguously assigned to a CAC.
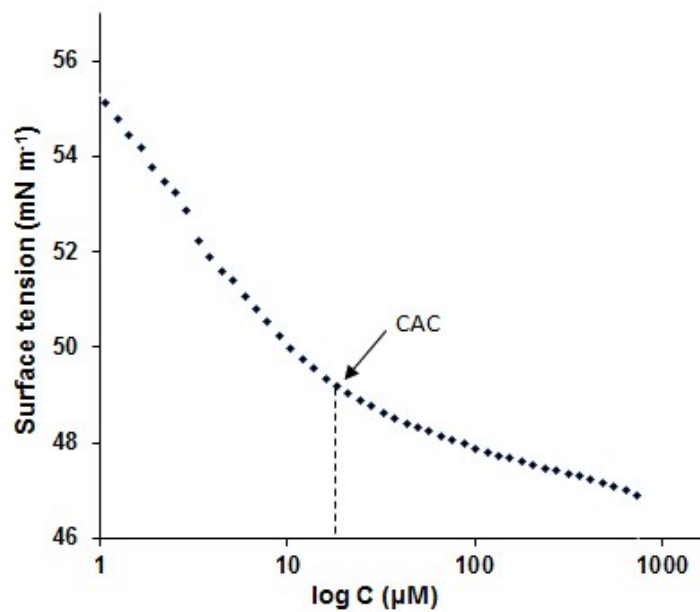
Figure S8. Surface tension (γ) plotted vs. log C (star copolymer concentration). Determination of CAC of star D-sorbitol[PCL_{18}-b-$PEP_{27}OH_6$] (2200:3700) g/mol diblock copolymer following the Wilhelmy plate method. The critical point (CAC) might be estimated at the intersection between the two different linear regimes of the curve to be 21.2 μM (0.012 wt%).
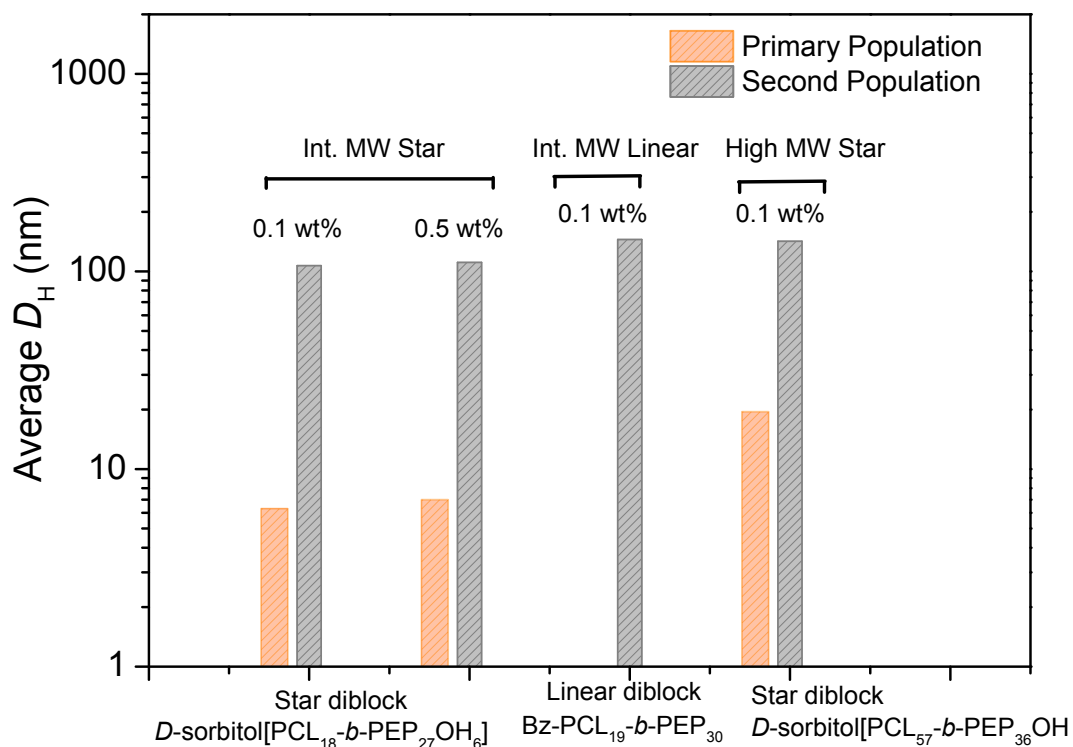
Figure S9. Hydrodynamic diameter (D_H) of high MW star PCL_n-b-PEP_m, Int. MW star by intensity-weighted distribution and analogue Int. MW linear diblock determined by direct dissolution in water at 0.1 wt% and 0.5 wt% by intensity distribution
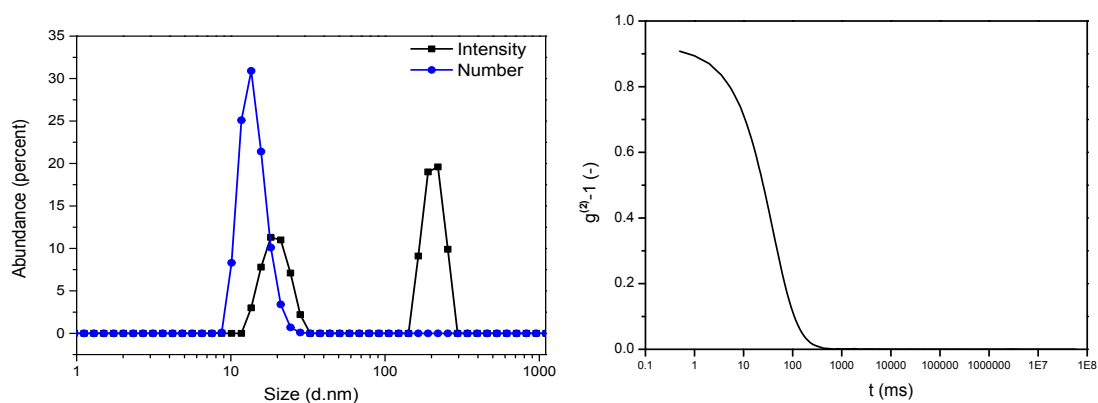

Figure S10. Intensity-weighted and number-weighted size distribution of star D-sorbitol[PCL_{57}-b-$PEP_{36}OH_6$] in an aqueous medium (0.1 wt%) (left) and autocorrelation function (right) obtained by nanoprecipitation method as analyzed by DLS.
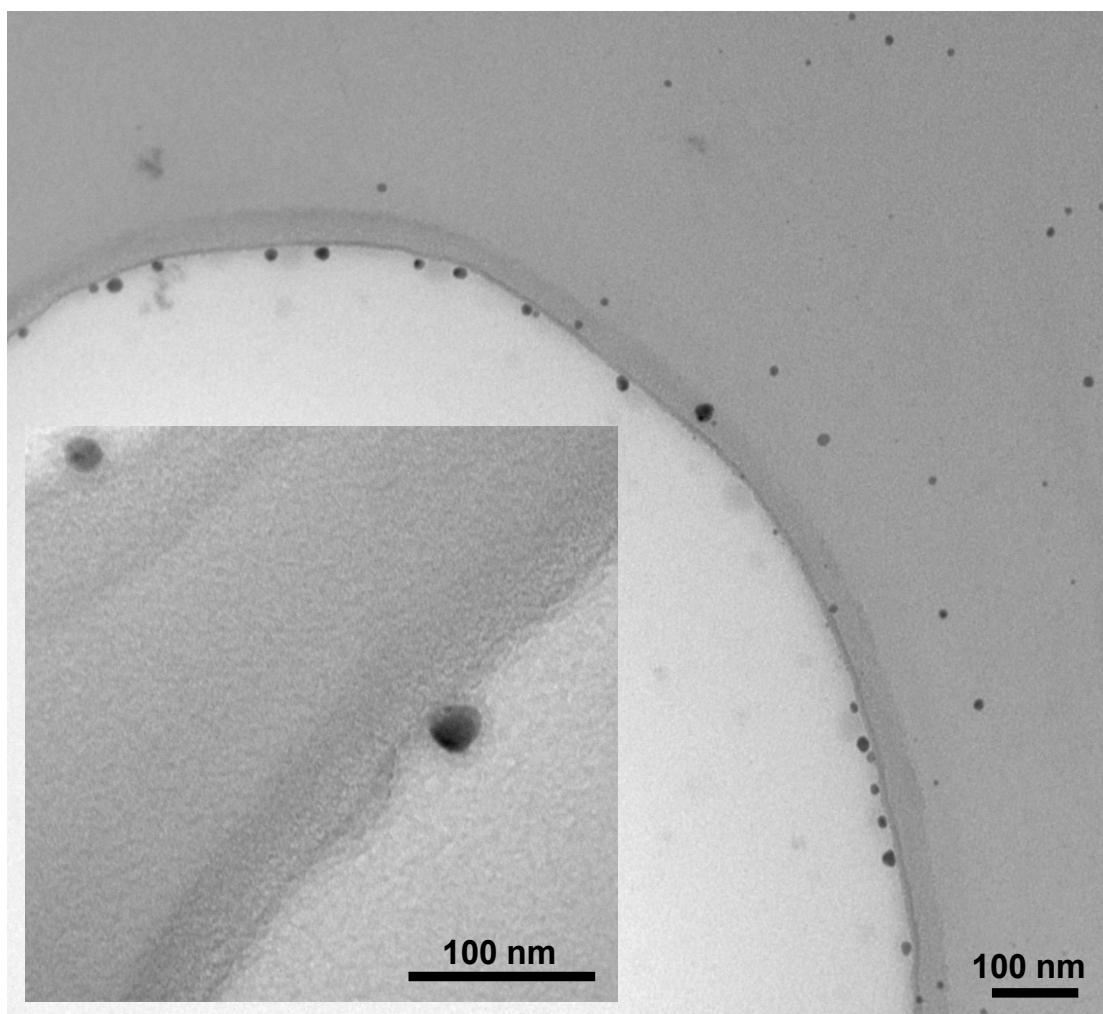
Figure S11. TEM images of star *D*-sorbitol[PCL$_{57}$-*b*-PEP$_{36}$OH$_6$] in an aqueous solution (1 mg/mL) by nanoprecipitation method on a graphene oxide coated holey carbon copper grid. Images acquired without staining at magnification × 60 000 and inset at a higher magnificent × 220 000 for clarity. Scale bar 100 nm for both.

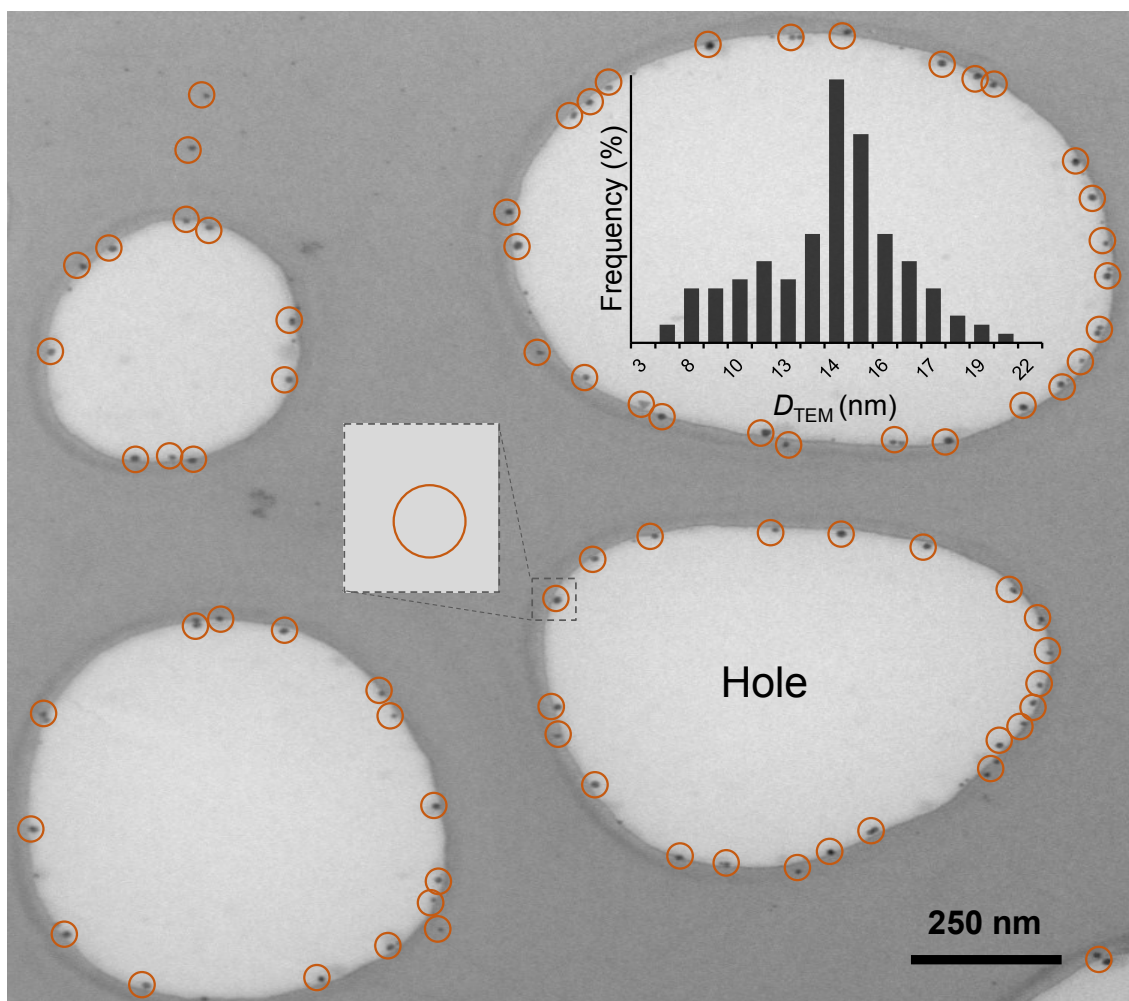**Figure S12**. TEM images and size distribution histogram (analyzed by ImageJ software) of a star *D*-sorbitol[PCL_{57}-*b*-$PEP_{36}OH_6$] in an aqueous solution (0.1 wt%) prepared by nanoprecipitation method on graphene oxide coated holey carbon copper grid. Uniformly sized spherical nanoparticles were pushed toward the edge of the hole in the carbon-polymer layer. Images acquired without staining. Scale bar 250 nm.

6. References

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